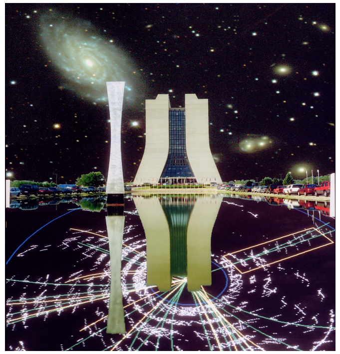


Measurements of Inclusive Jets and photon/Z/W+Jets at the Tevatron

M. Martínez-Pérez

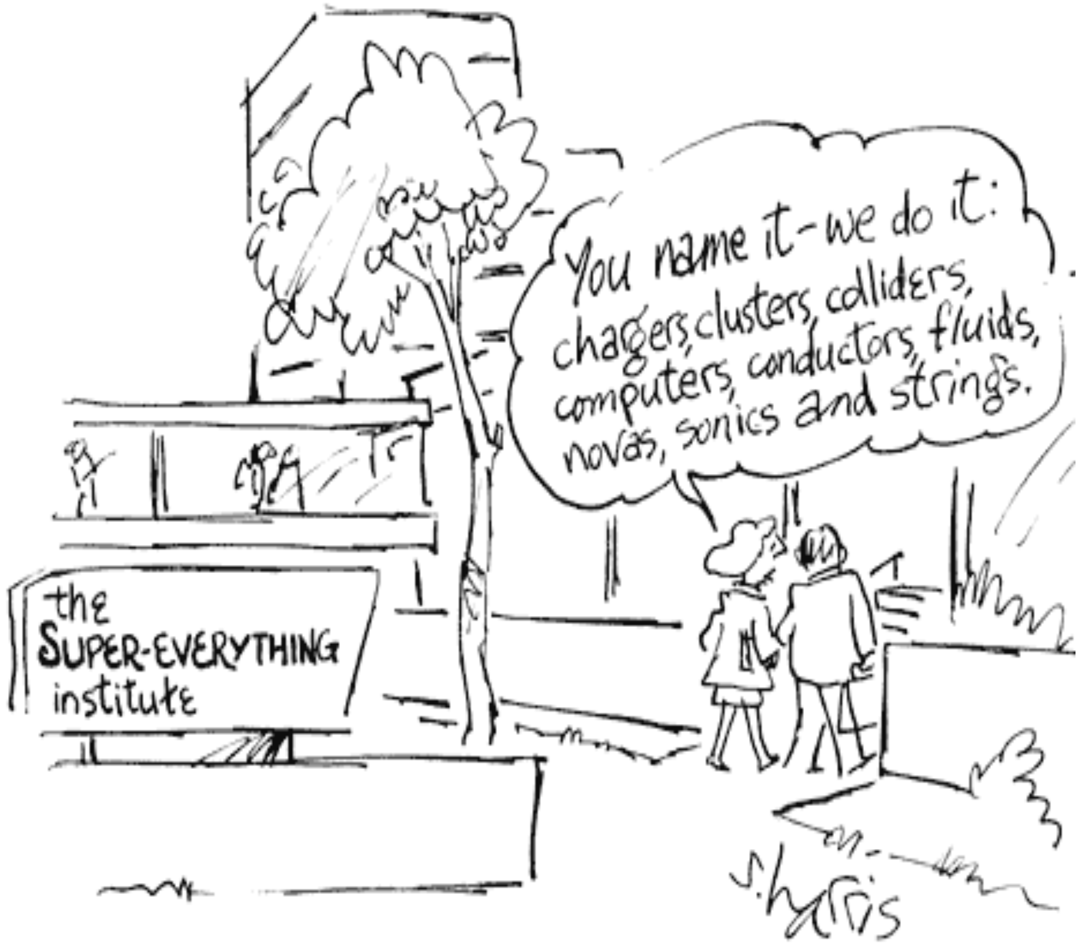
ICREA/IFAE-Barcelona

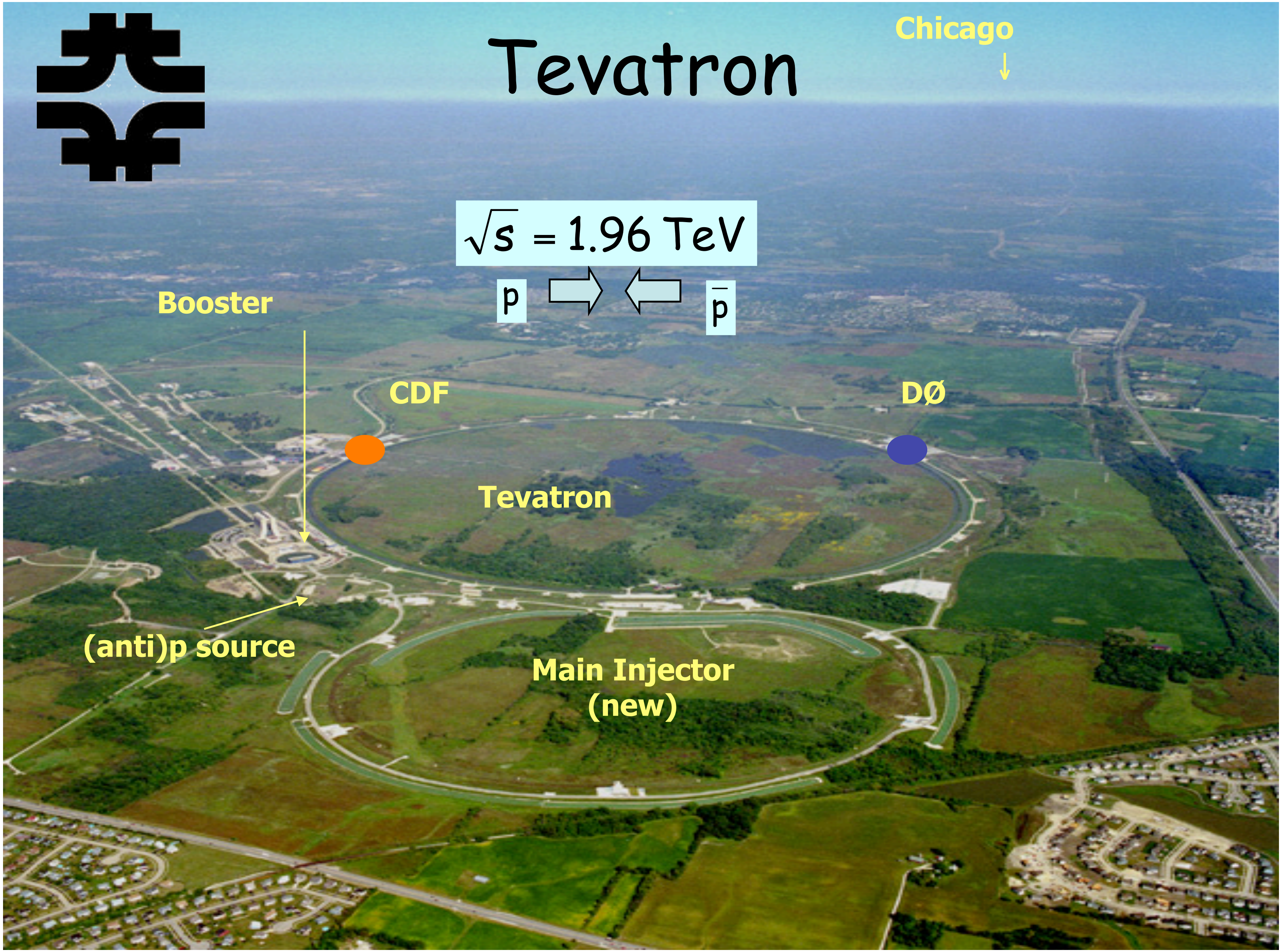
Results from CDF & D0 Collaborations

ASPEN WINTER 2009
Workshop on Physics at the LHC era

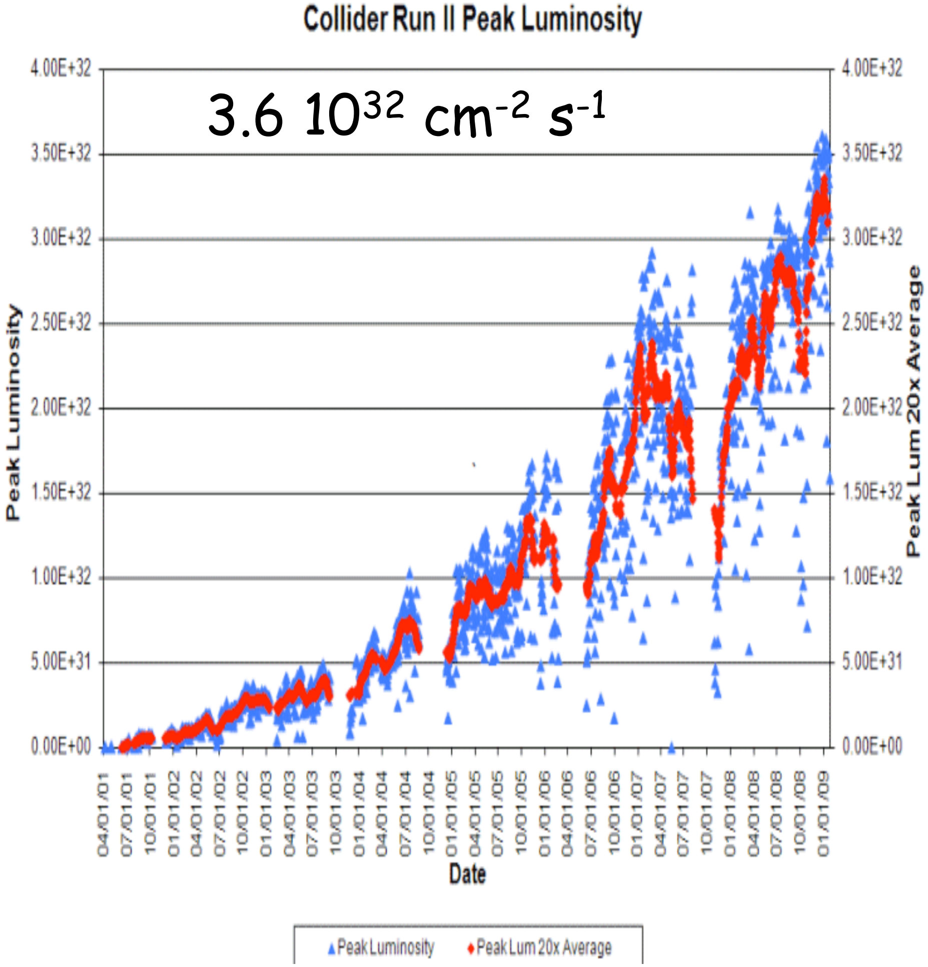
Outline

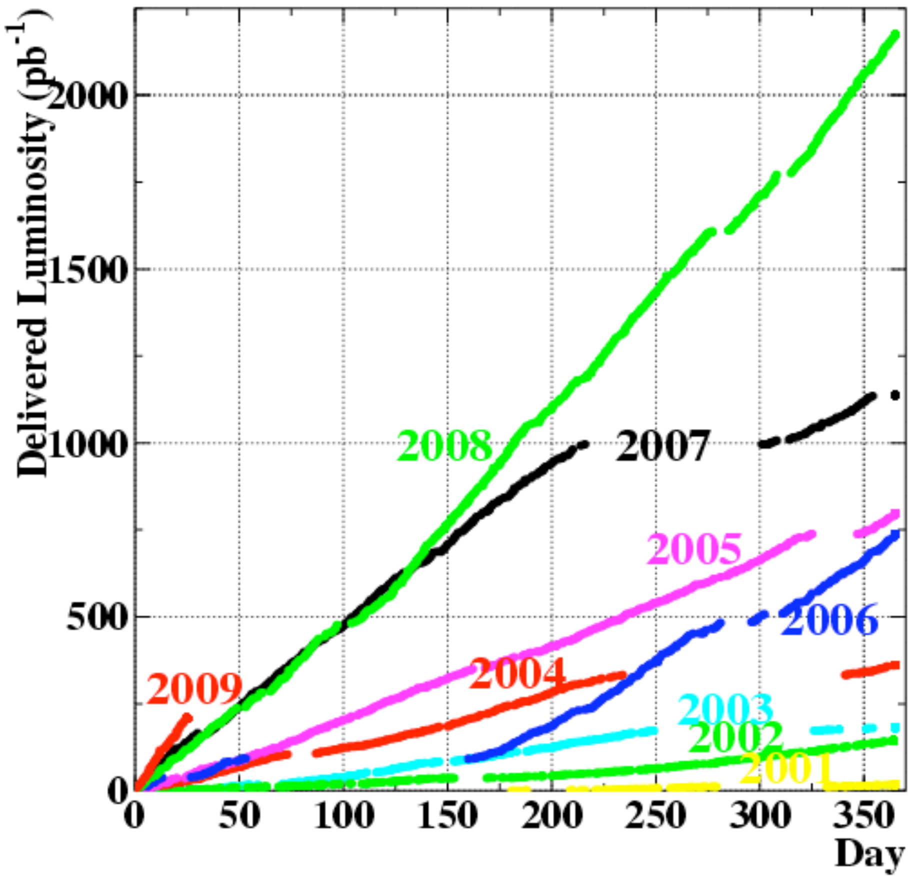
- Tevatron, CDF/D0
- Inclusive Jet Production
- Dijet Production
- Underlying Event Studies
- Prompt Photon Production
- Photon+Jet & Photon+b/c
- Z+jets Production
- W+jets Production
- Final Remarks




Tevatron
Chicago
$\sqrt{s} = 1.96$ TeV
p
$\bar{p}$
Booster
CDF
DØ
Tevatron
(anti)p source
Main Injector
(new)

Tevatron Performance



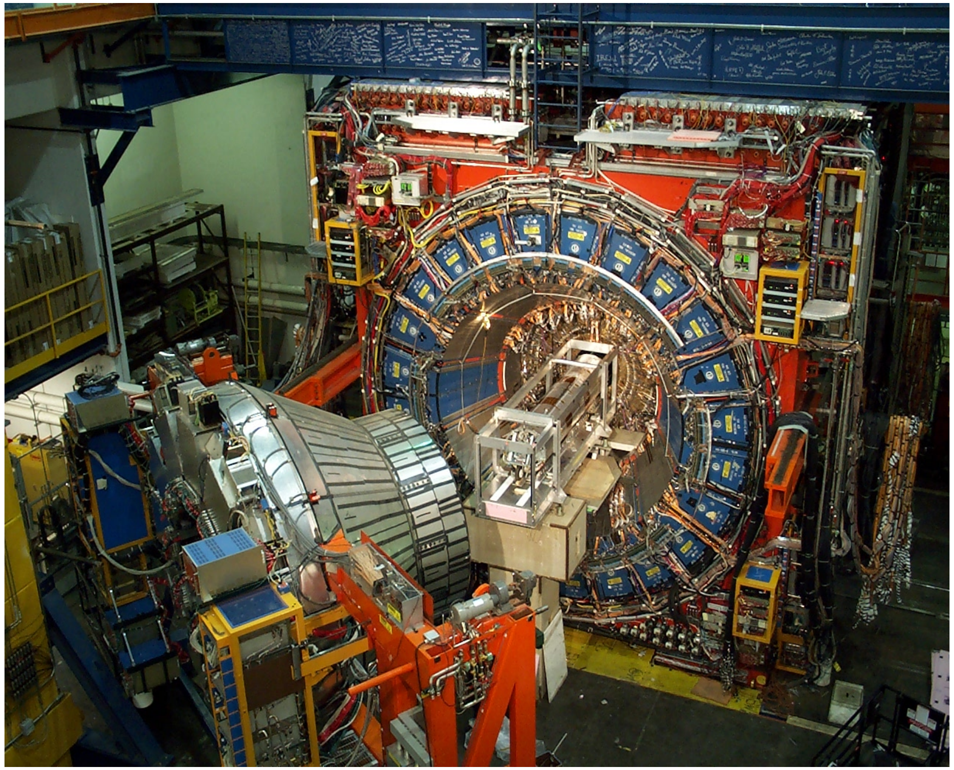


Tevatron delivered > 6 fb^{-1}
(8 fb^{-1} expected by end FY09)

Ongoing discussion for FY2010
(we could sum up to 10 fb^{-1})

(Run I : 120 pb^{-1})

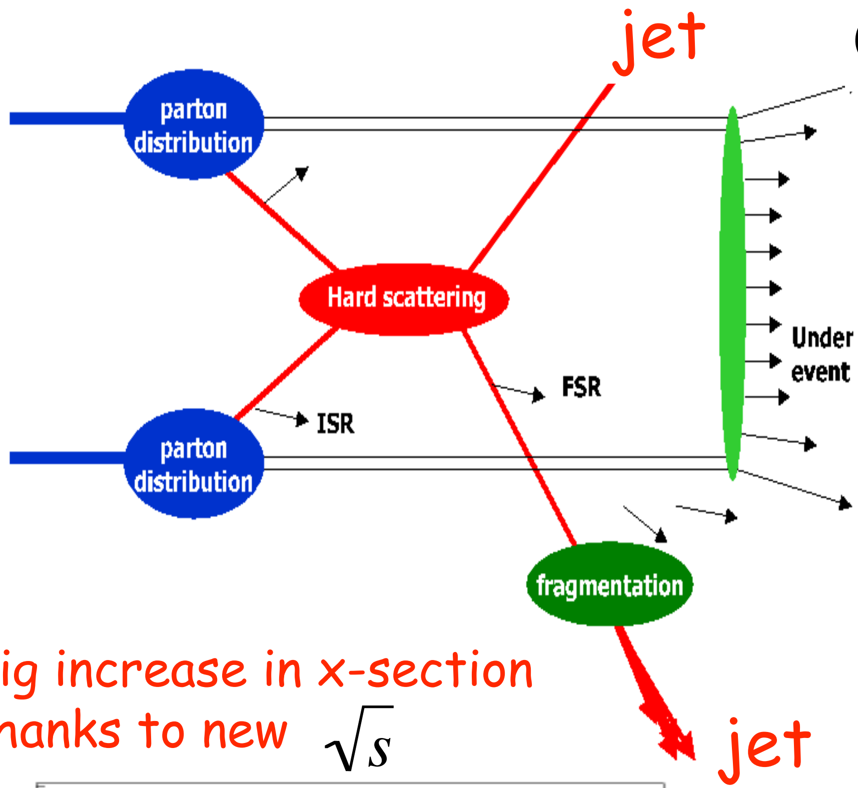
CDF & D0 Detectors

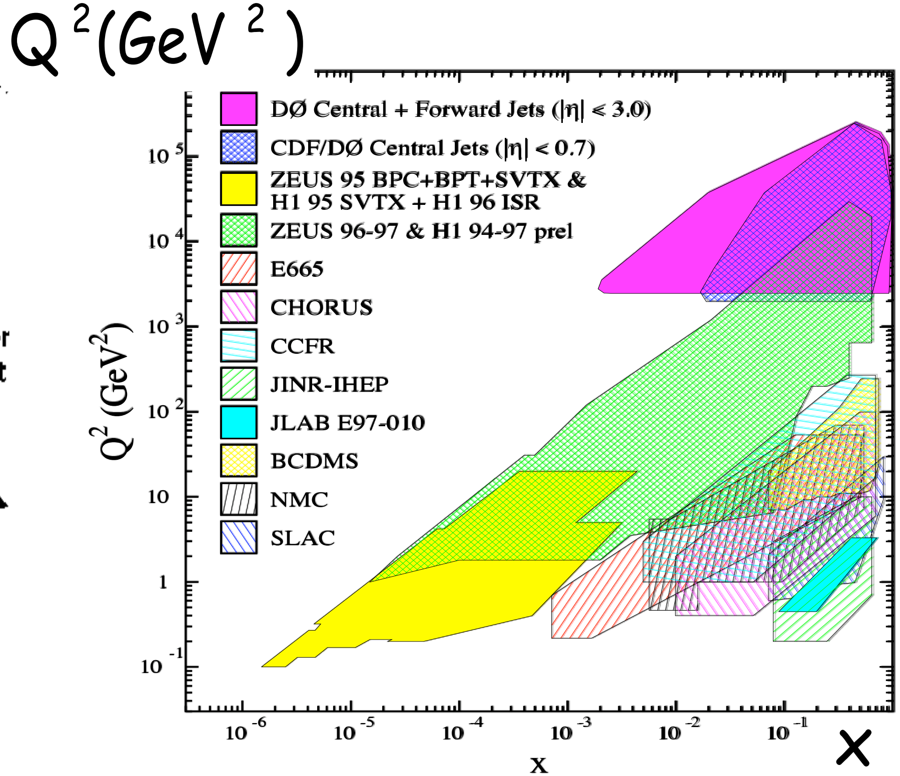


CDF & DØ operating well and recording physics quality data with very high efficiency (~85%)

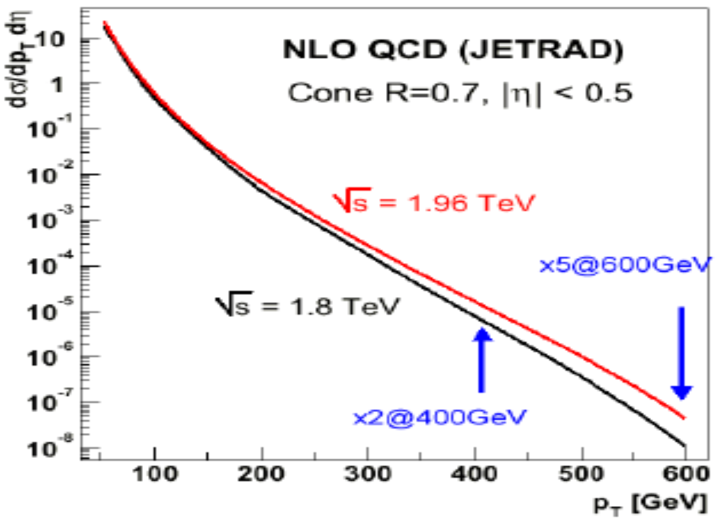
Both experiments have already collected > 5 fb-1 on tape

High Pt Jet Physics at 2 TeV





Big increase in x-section thanks to new $\sqrt{s}$



Huge step forward in Run II

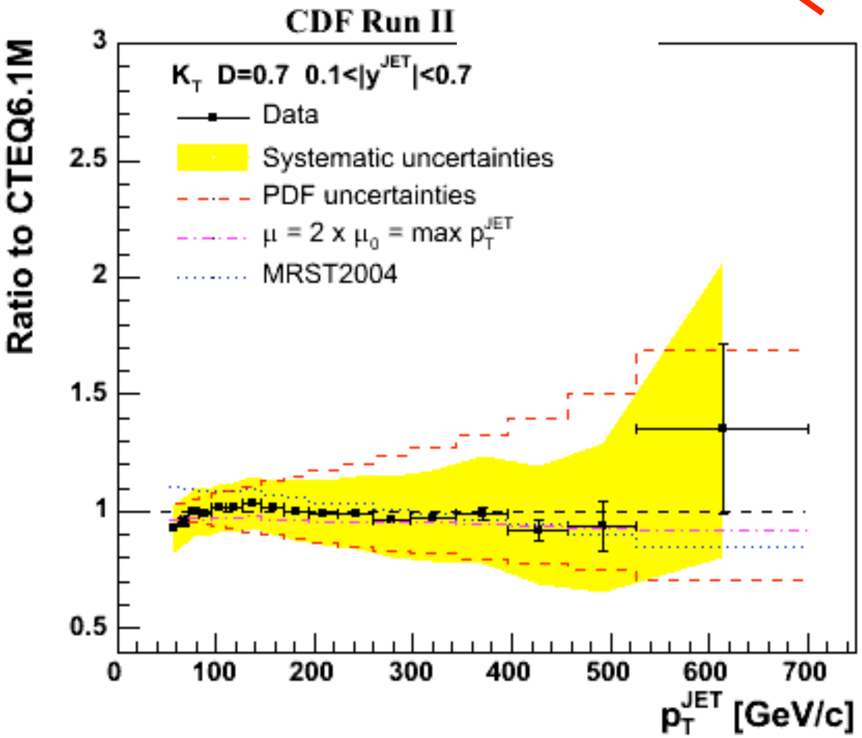
- Pt range increased by 150 GeV/c
- Measurements in wide rapidity region
- Use of K_T and cone jet algorithms
- Inclusion of non-pQCD contributions

Inclusive Jet Production

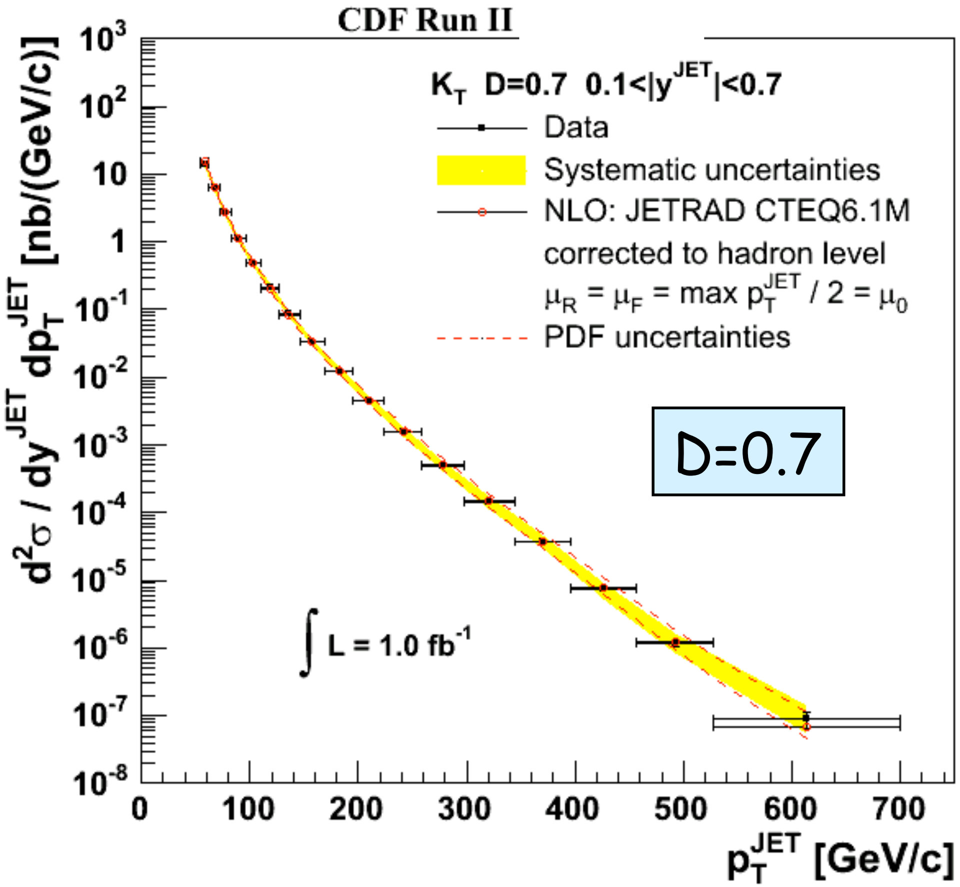
- Inclusive K_T algorithm

$$d_{ij} = \min(P^2_{T,i}, P^2_{T,j})\frac{\Delta R^2}{D^2}$$

$$d_i = (P_{T,i})^2$$



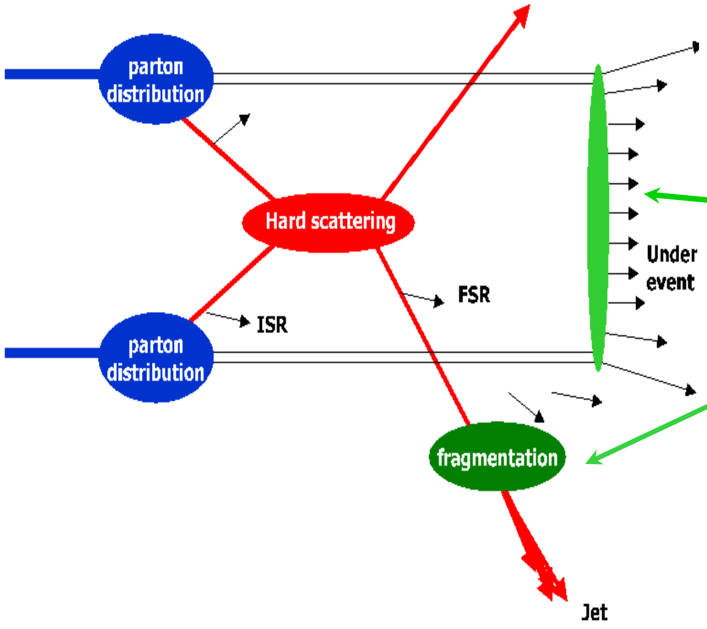
NLO pQCD is corrected for Hadronization & Underlying Event (this is important at low Pt)



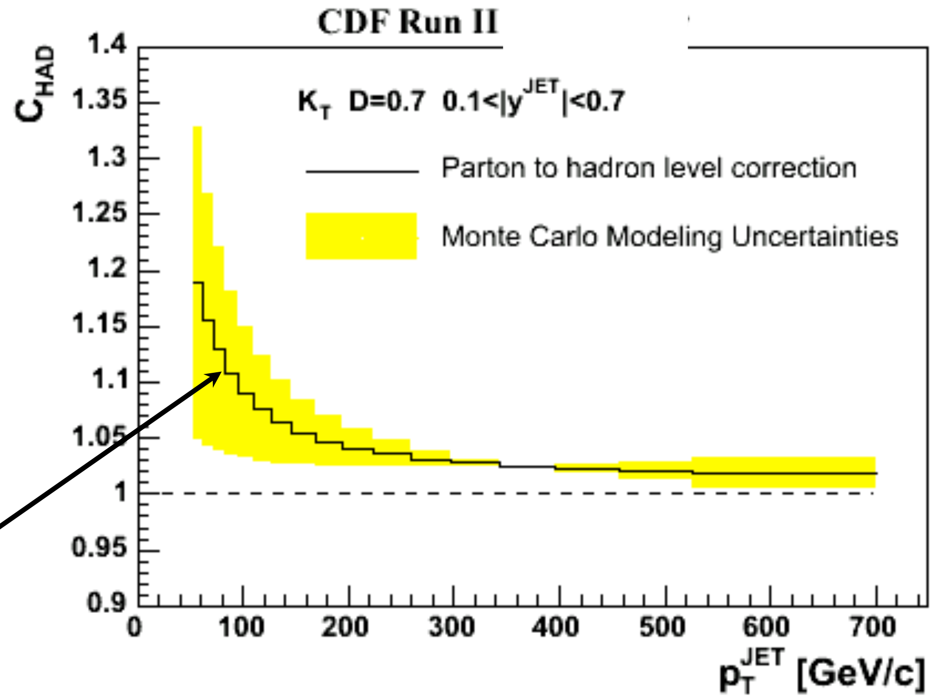
- Good agreement Data vs Theory
  - Data uncertainty -> 2-2.7% e-scale
  - pQCD uncertainty -> PDFs
- K_T robust in hadron collisions

→ relevant for LHC strategies

Non-pQCD Contributions



- Non-pQCD contributions
- Underlying Event
(remnant-remnant interactions)
- Fragmentation into hadrons



Underlying Event and Fragmentation contributions must be considered before comparing to NLO QCD predictions
(only way to perform a fair comparison)

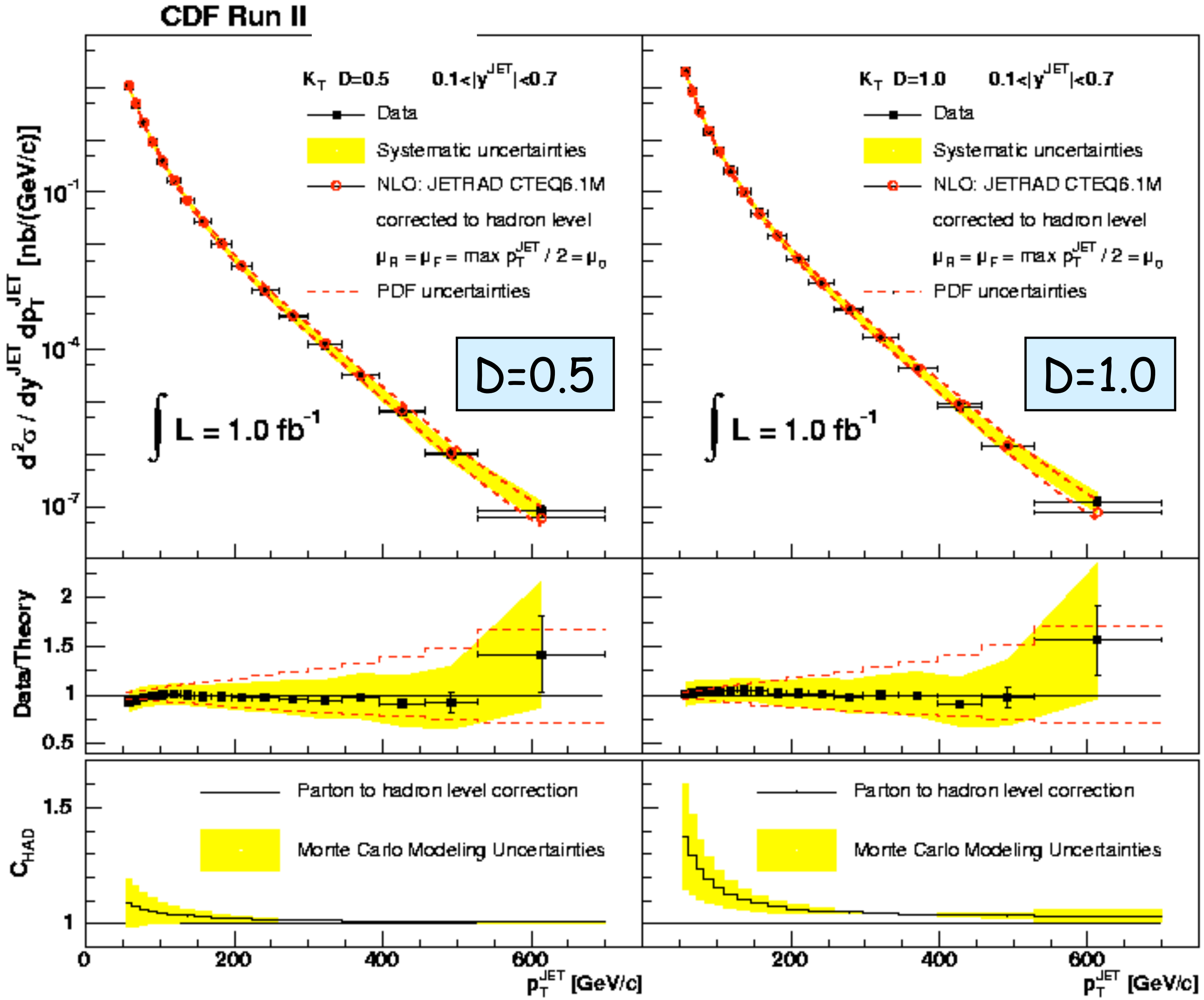
Precise measurements at low Pt require good modeling of the non-pQCD terms

Dedicated measurements are needed to validate the Monte Carlo modeling

$$d_{ij} = \min(P^2_{T,i}, P^2_{T,j})\frac{\Delta R^2}{D^2}$$

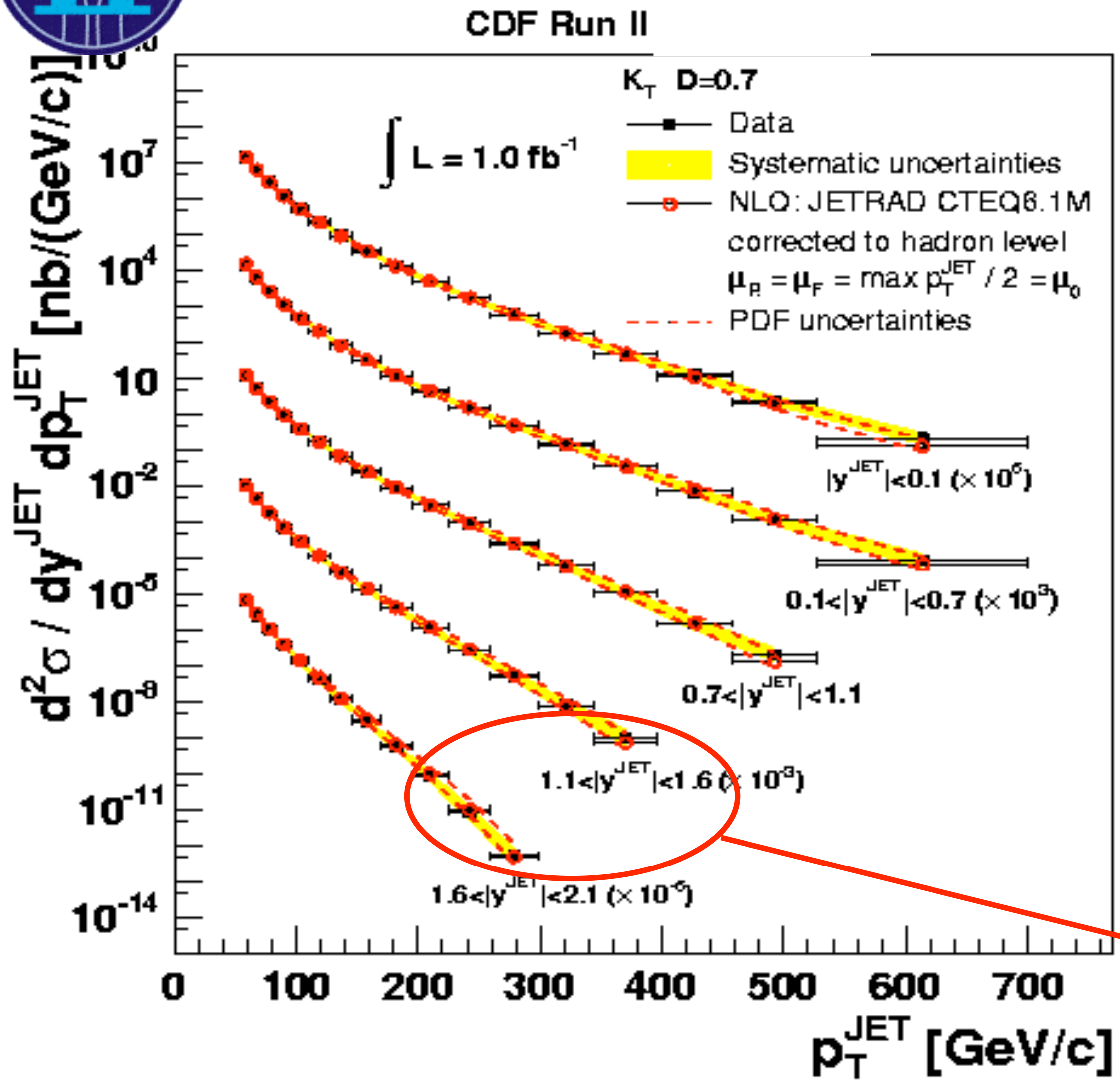
K_T Jets vs D

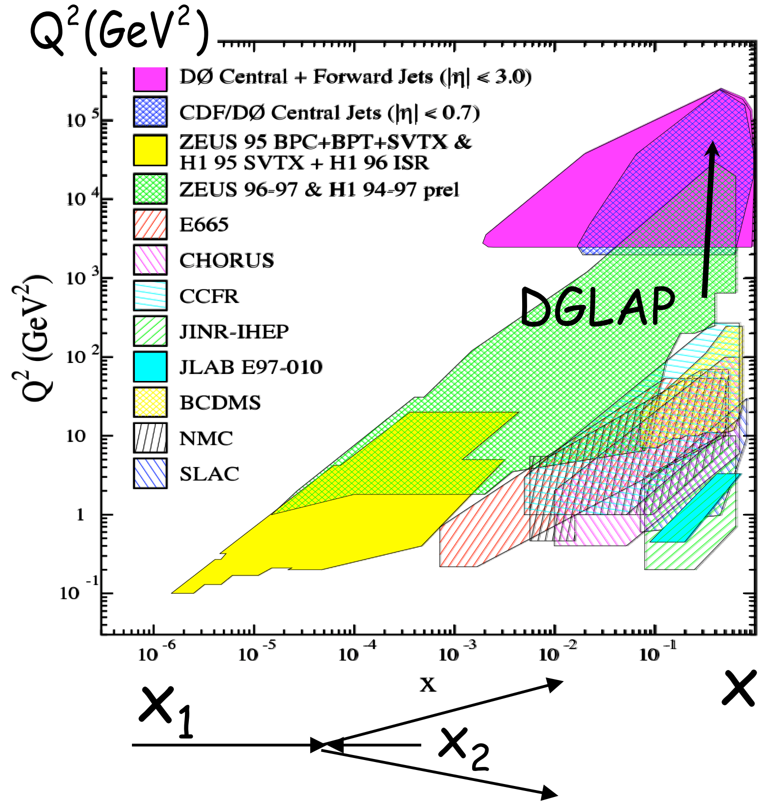
1 fb^{-1}

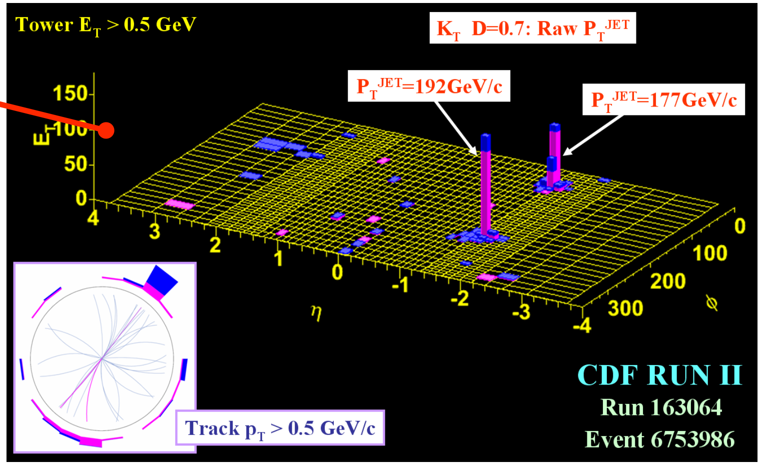


As D increases the required non-perturbative corrections increase at low P_T

Measurement in five $|y^{jet}|$ ranges

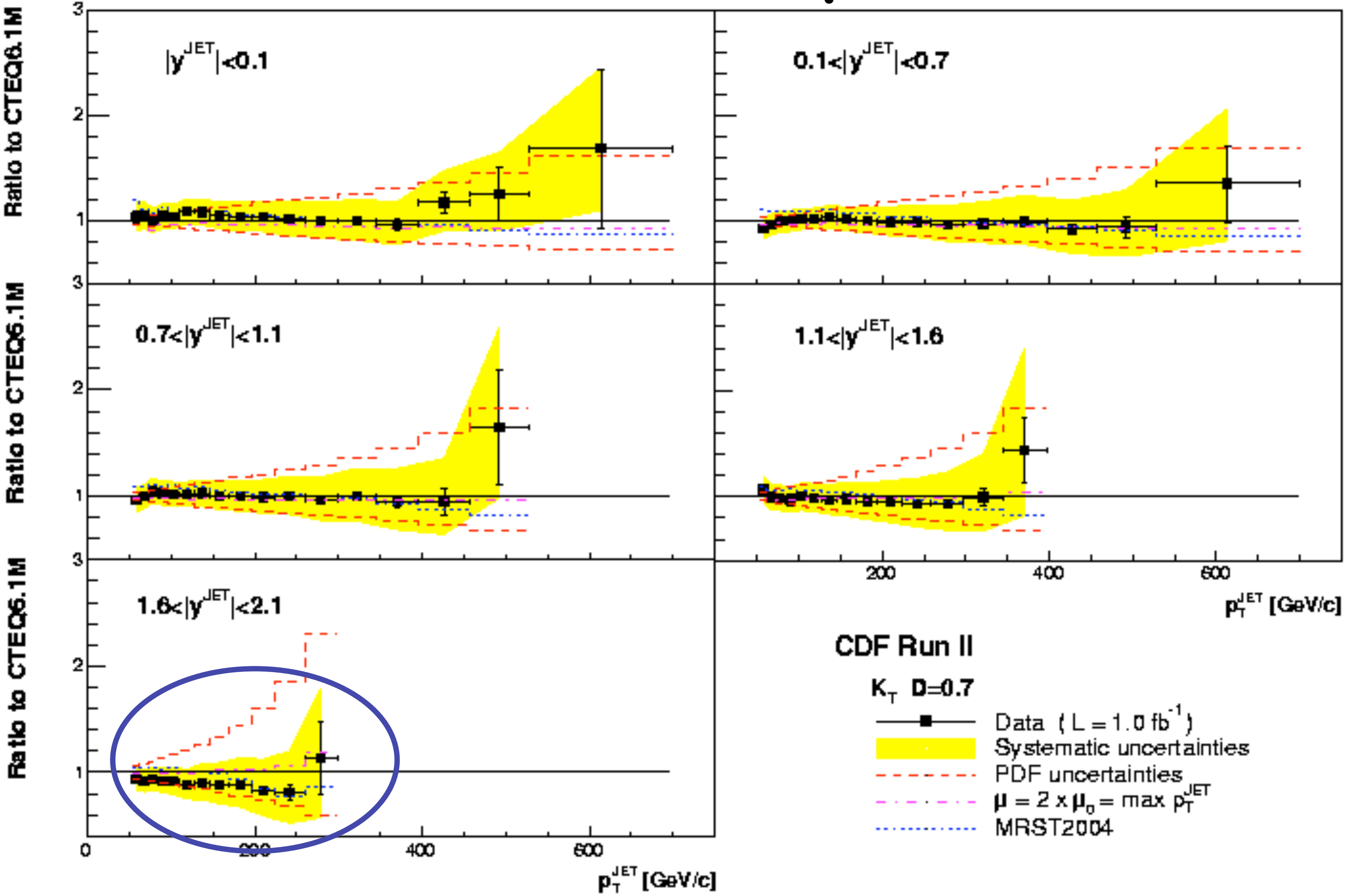






Forward jet measurements further constrain the gluon PDF in a region in P_T where no new physics is expected

Ratio Data/pQCD NLO

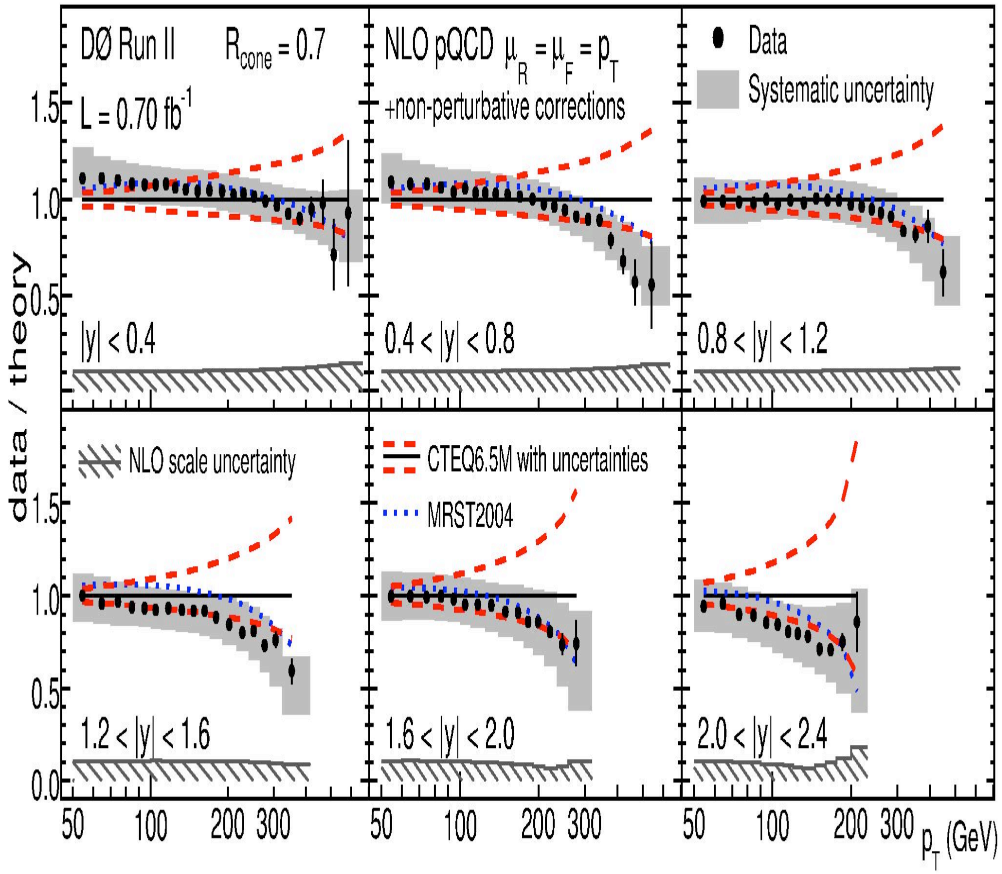


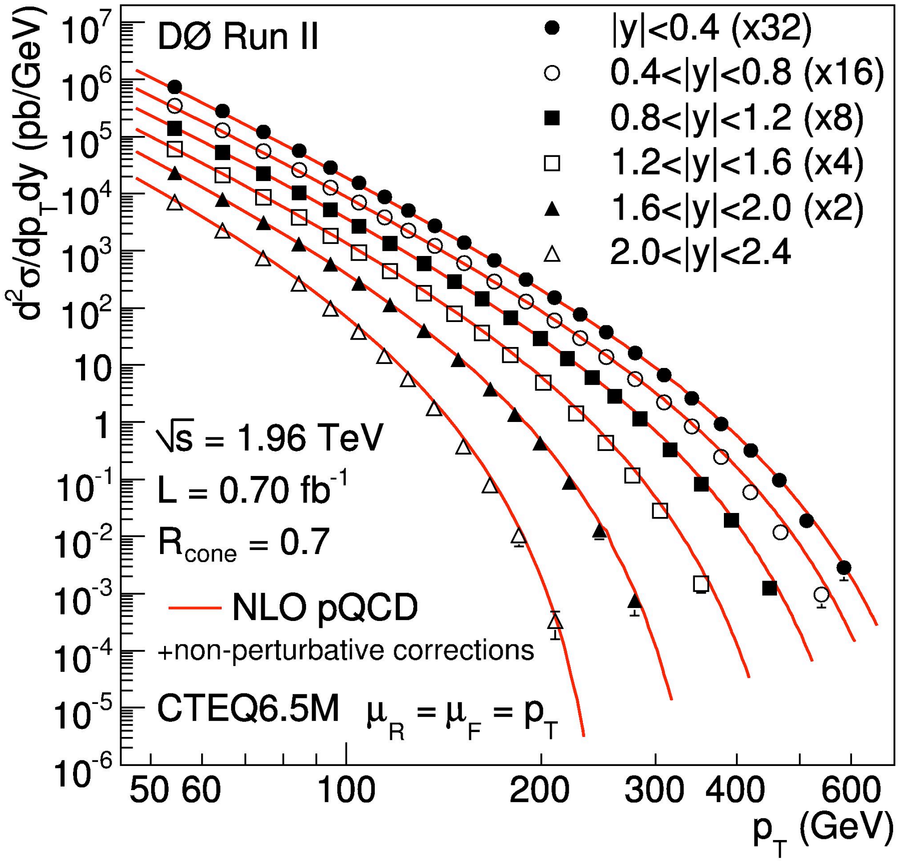
Data uncertainty smaller than that on pQCD NLO

Data prefer the lower edge of the PDF uncertainty band

Latest D0 Jet Results

Using cone-based Midpoint Algorithm (R=0.7)





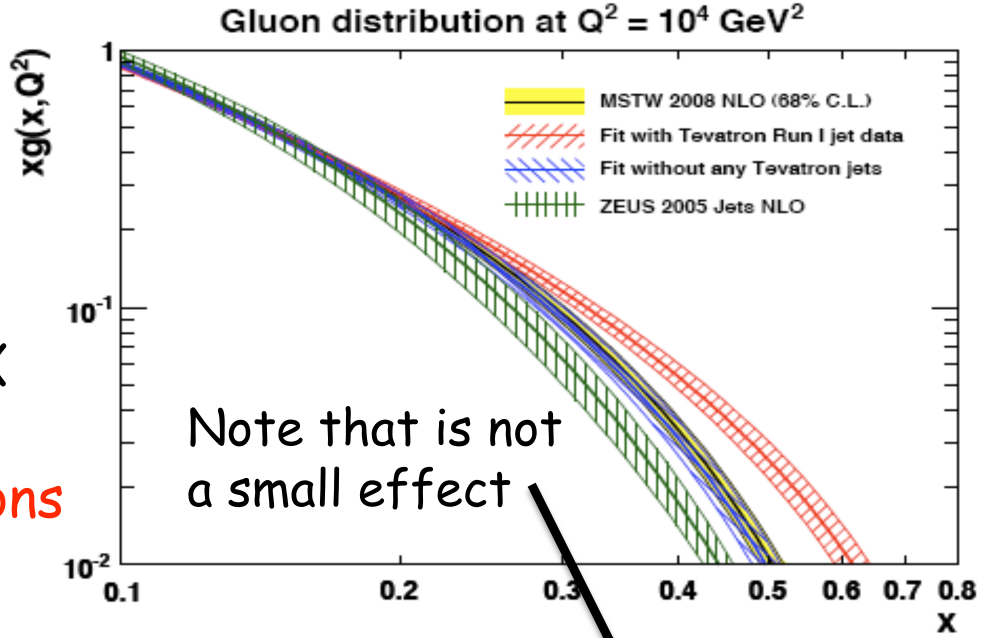
Similar conclusions using the midpoint algorithm ….and reduced systematic uncertainties on the absolute jet energy scale (1.2% - 2%)

New Gluon (MSTW08) (hep-ph:09010002)

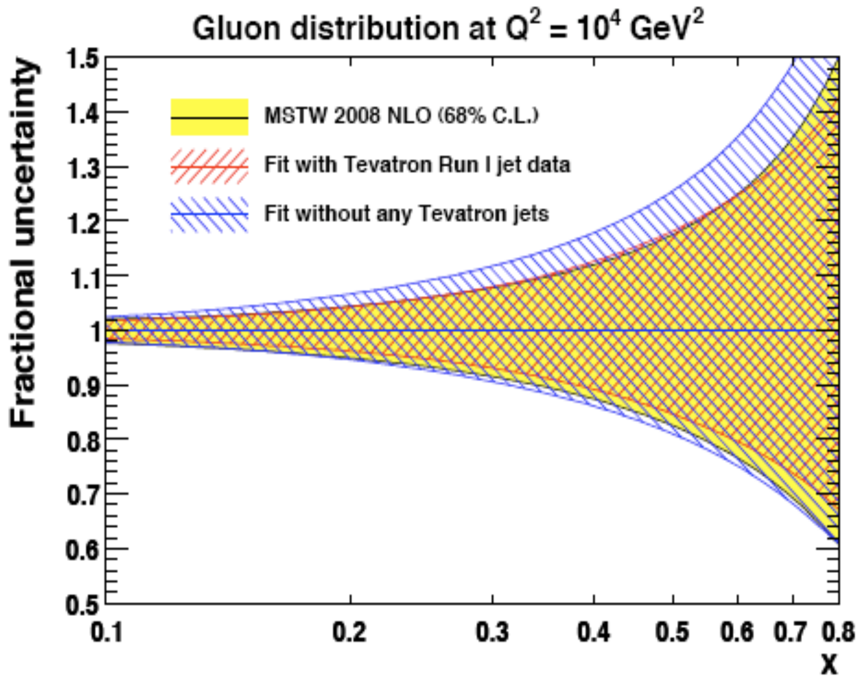
New MSTW analysis:

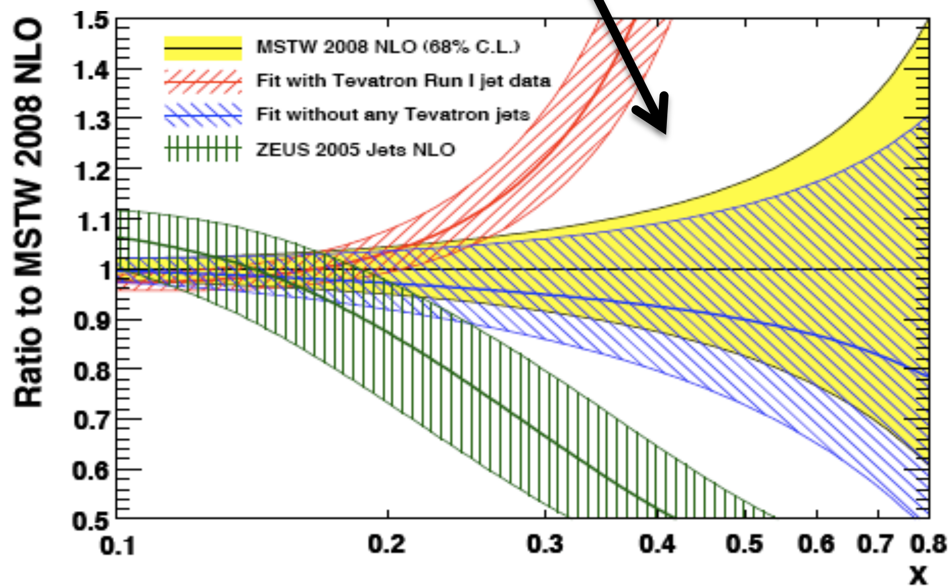
- Using CDF Kt and D0 Midpoint
- CDF and D0 data consistent

- Data dictate less gluons at high-X
- Reduced gluon PDF uncertainty
- Reduced gluon-driven cross sections

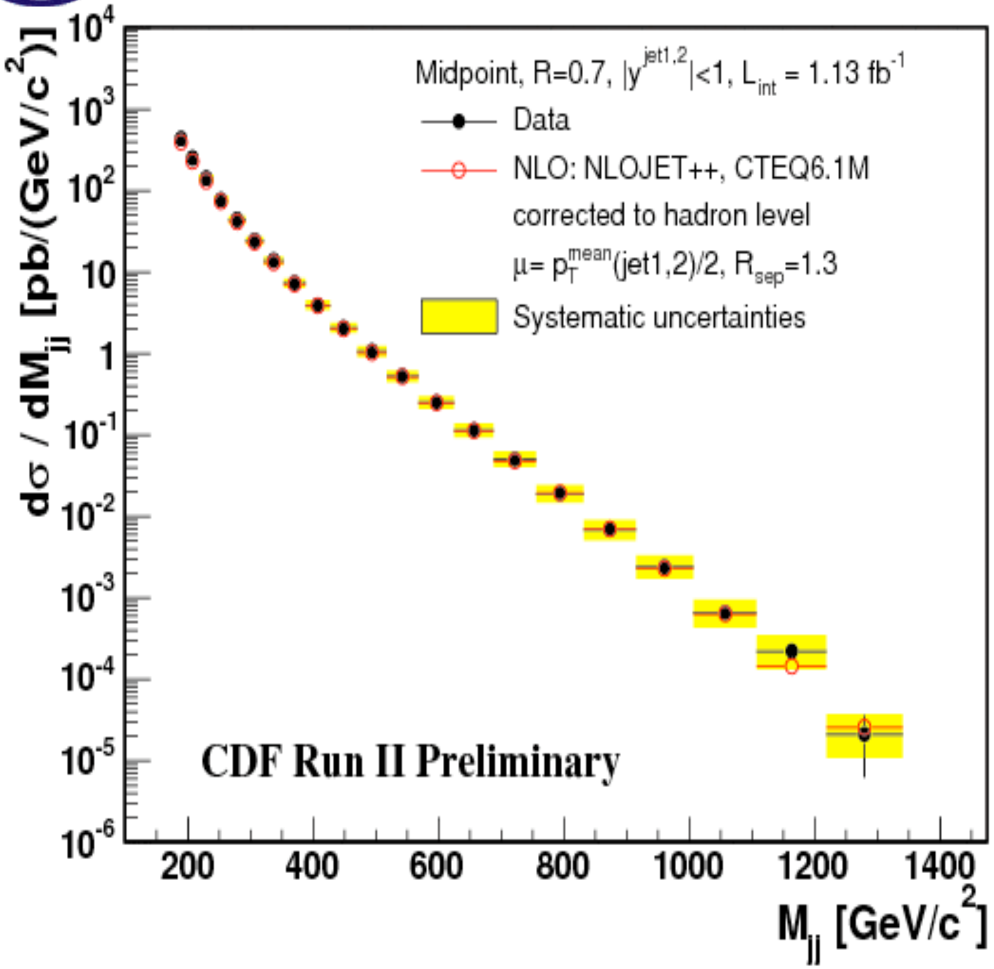


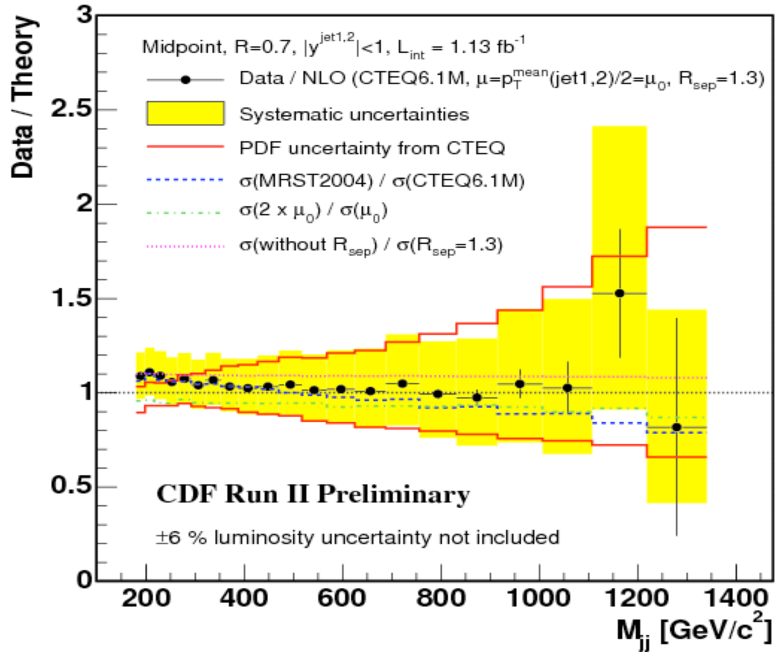
Note that is not a small effect





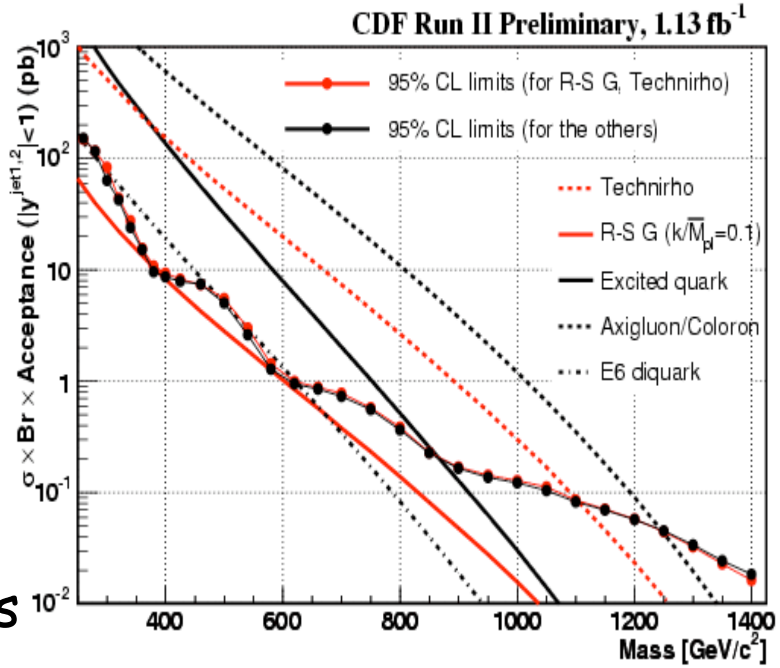
Dijet Mass





Dijet Mass distribution in good agreement with NLO pQCD predictions

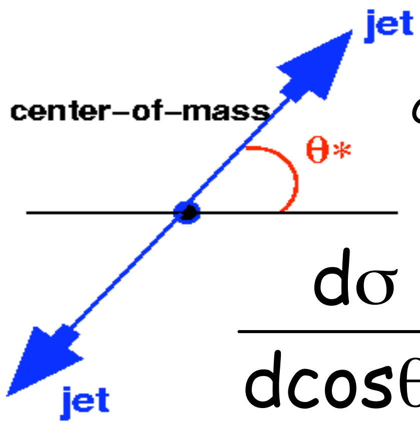
→ Limits on new particles decaying into jets



Dijet Angular Distribution

Current uncertainties on jet energy scale and gluon PDFs at high x makes difficult to claim new physics from the tail of the Pt distribution.....

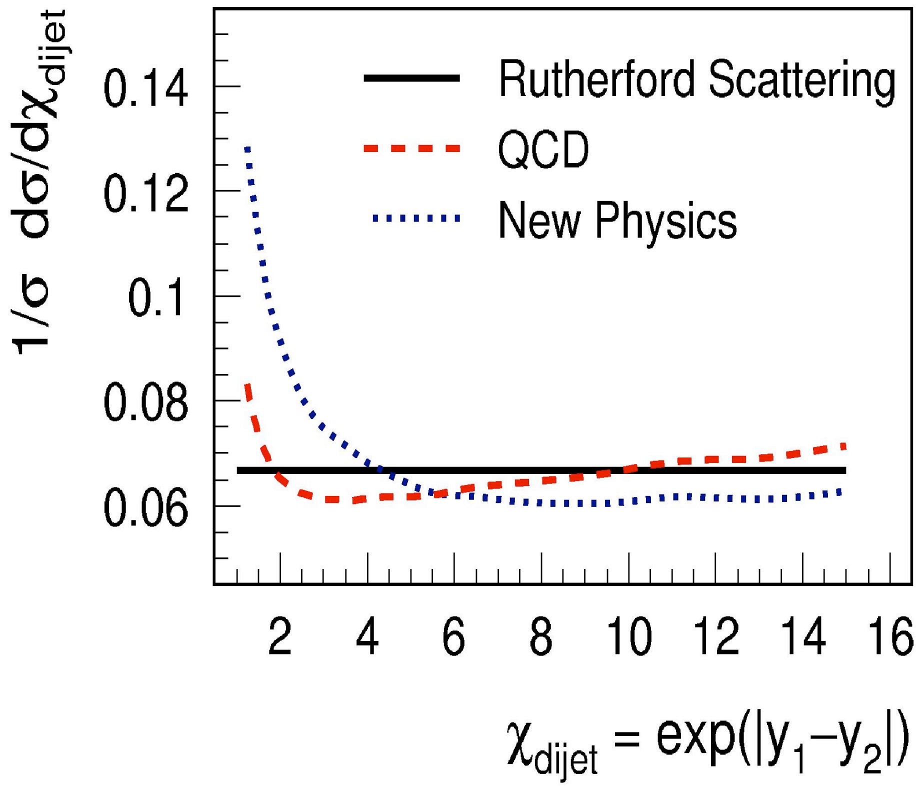
......how about QCD dynamics ?



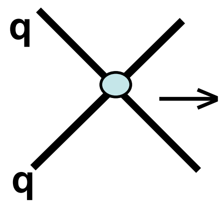
$$\cos\theta^* = \tanh\left(\frac{\eta_{jet1} - \eta_{jet2}}{2}\right)$$

$$\frac{d\sigma}{d\cos\theta^*} \approx \frac{1}{(1-\cos\theta^*)^2}$$

(dominant t-channel gluon exchange)



The presence of quark compositeness at scale Λ would add terms like

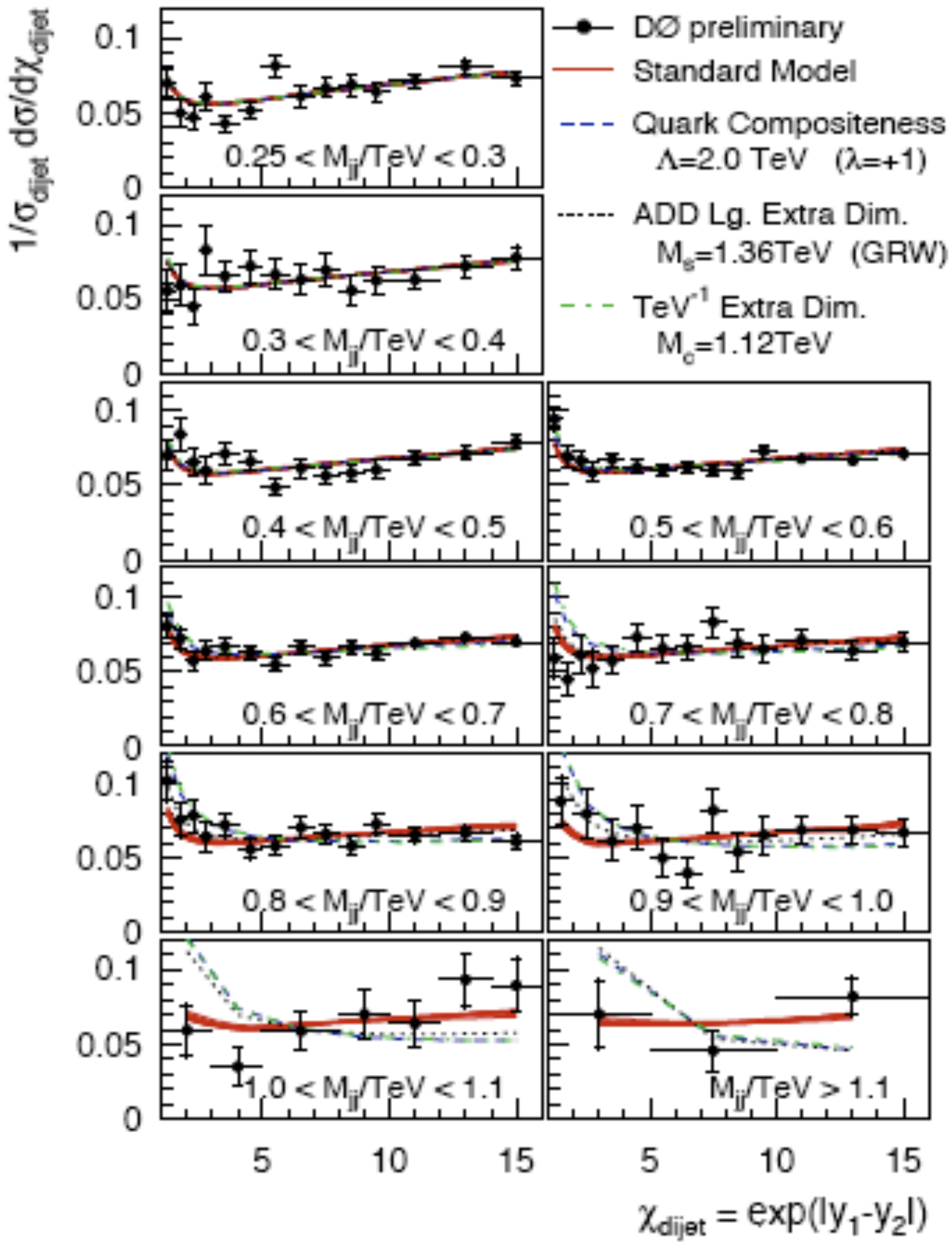


$$\rightarrow \frac{g}{\Lambda^+} \qquad \frac{d\sigma^{new}}{d\cos\theta^*} \approx \frac{1}{(1+\cos\theta^*)^2}$$

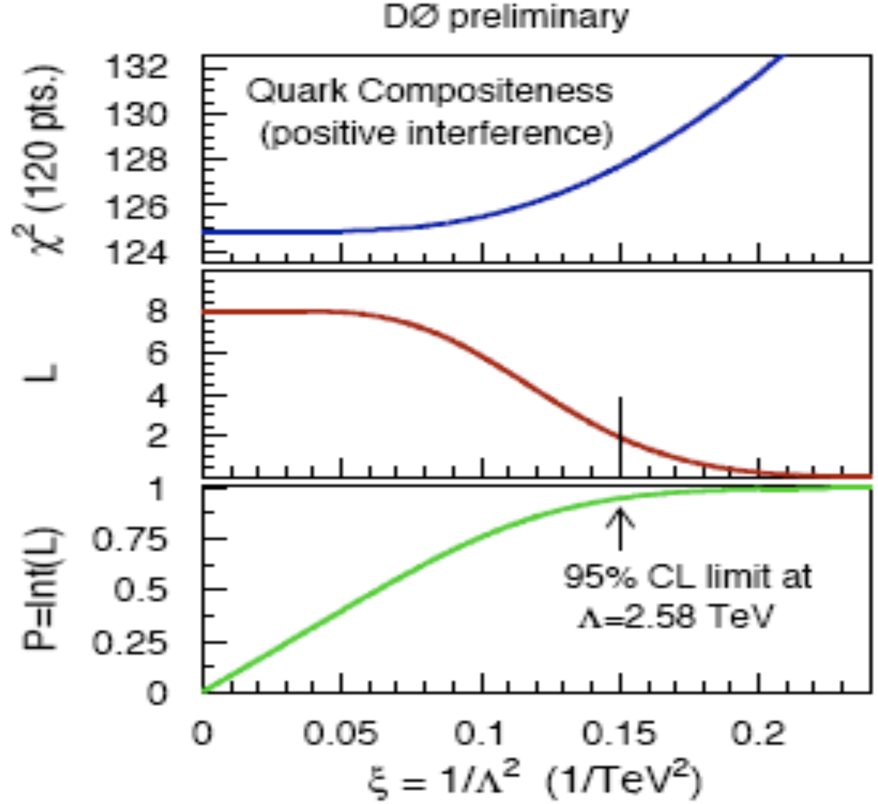
We define then

$$\chi = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

..this also tells you gluon has spin 1..



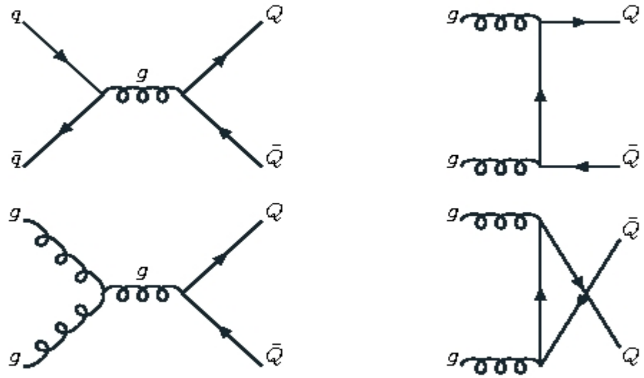
$$\sigma_{\mathrm{NP}} = \mathrm{SM} + \frac{\lambda}{\Lambda^2}\,\mathrm{Interf.} + \frac{\lambda^2}{\Lambda^4}\,\mathrm{NP}$$

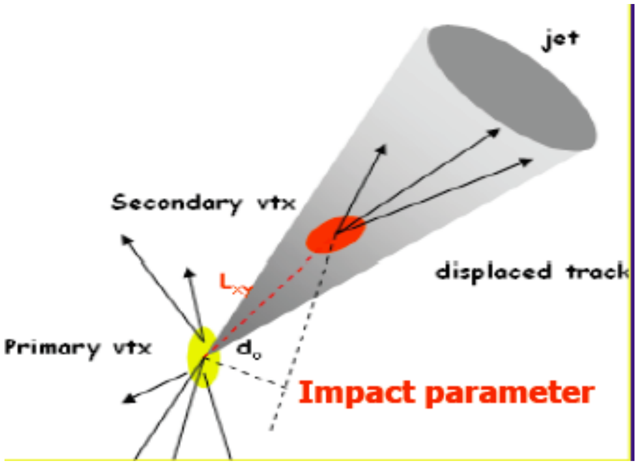


This analysis excludes compositeness with scale less than 2.58 TeV@ 95%CL

Good agreement with QCD predictions

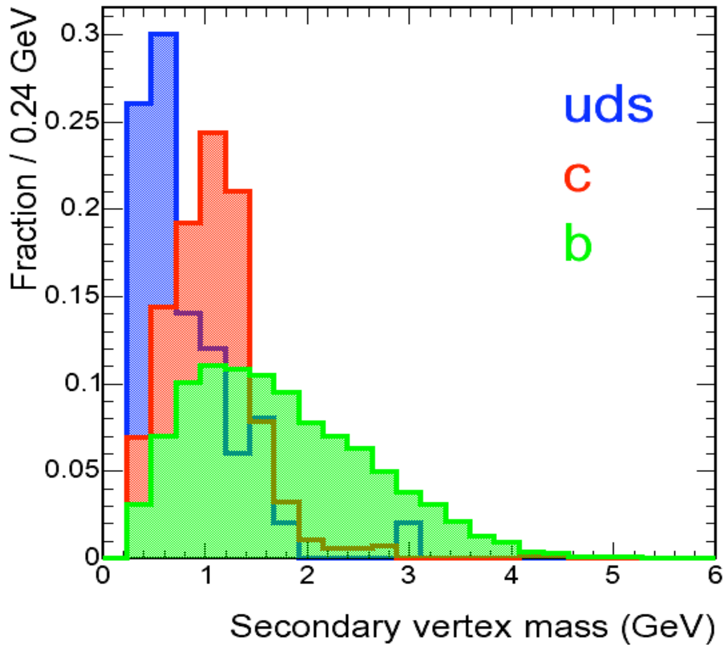
Dijet Production ($b\bar{b}$)

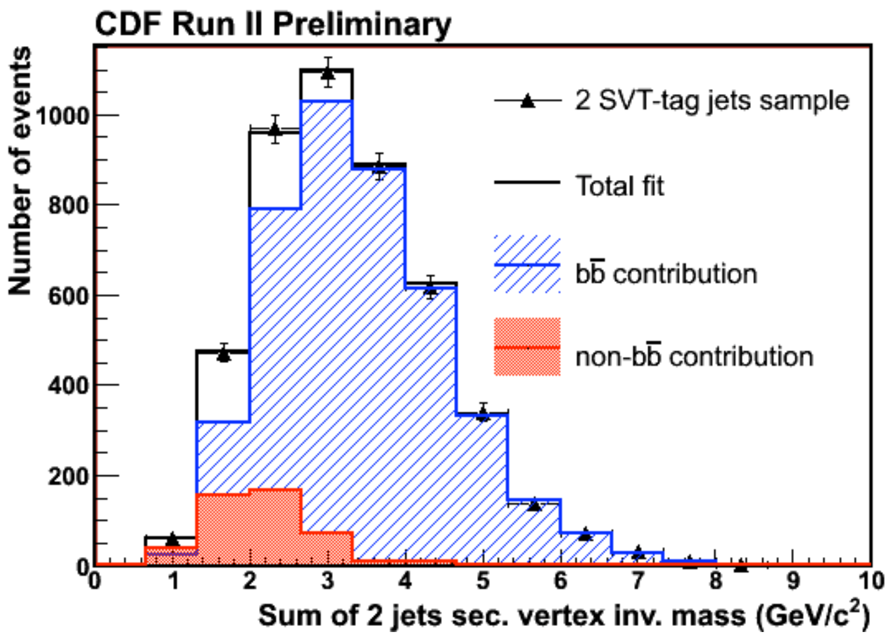




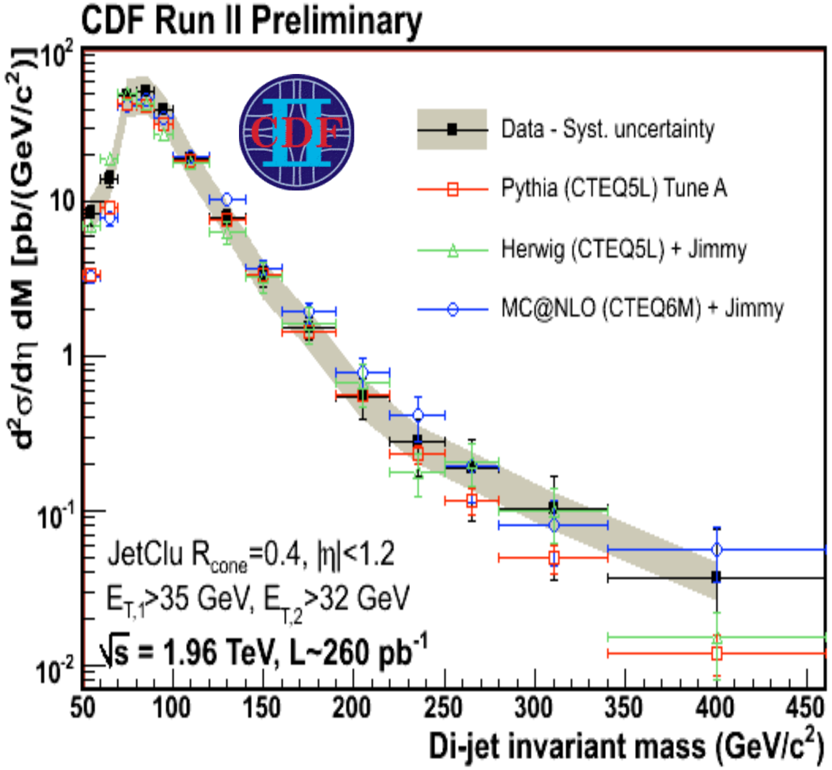
2 jets with $E_T >$ 35 (32) GeV and $|\eta| < 1.2$
Identified secondary decay vertex (b-tagged)

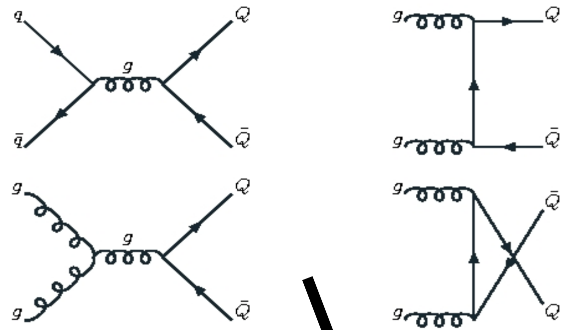
Secondary vertex mass used to separate bottom from (uds + c) contributions

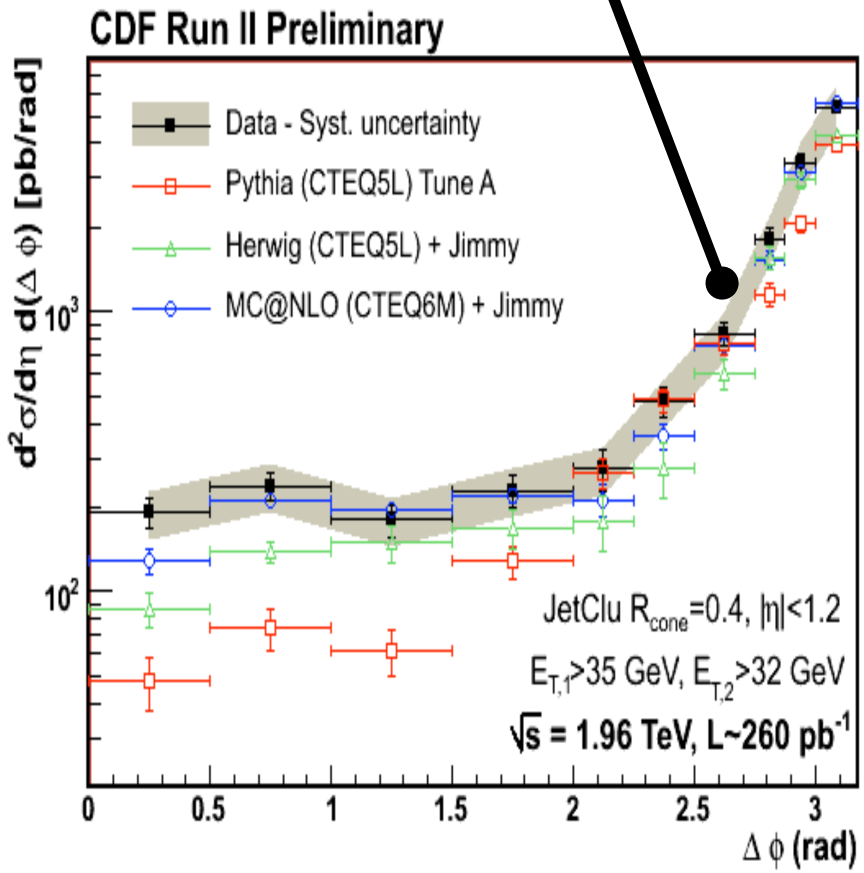


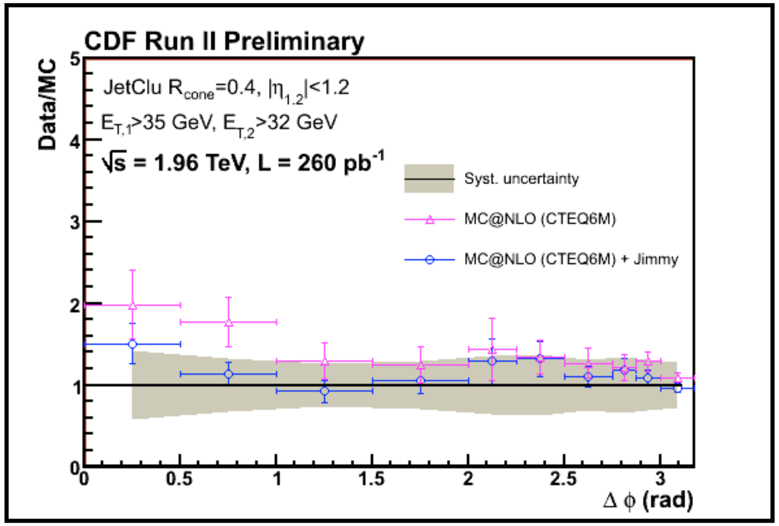


Dijet Production ($b\bar{b}$)



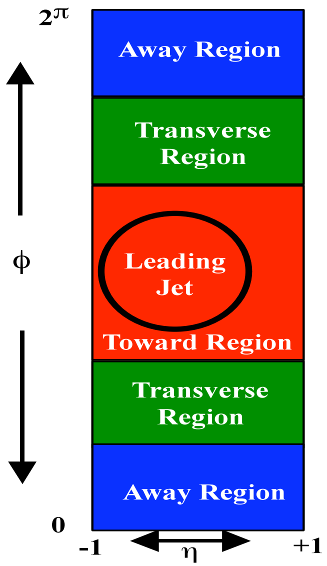


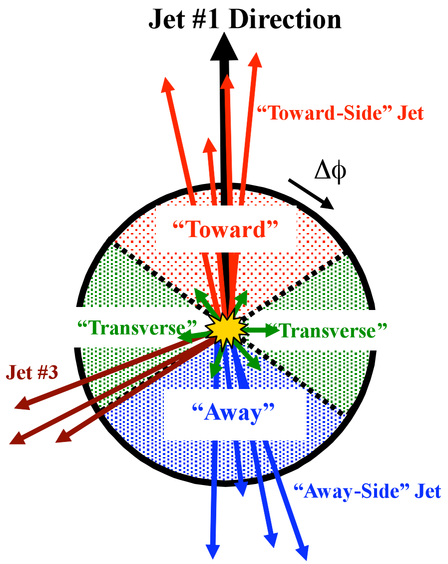




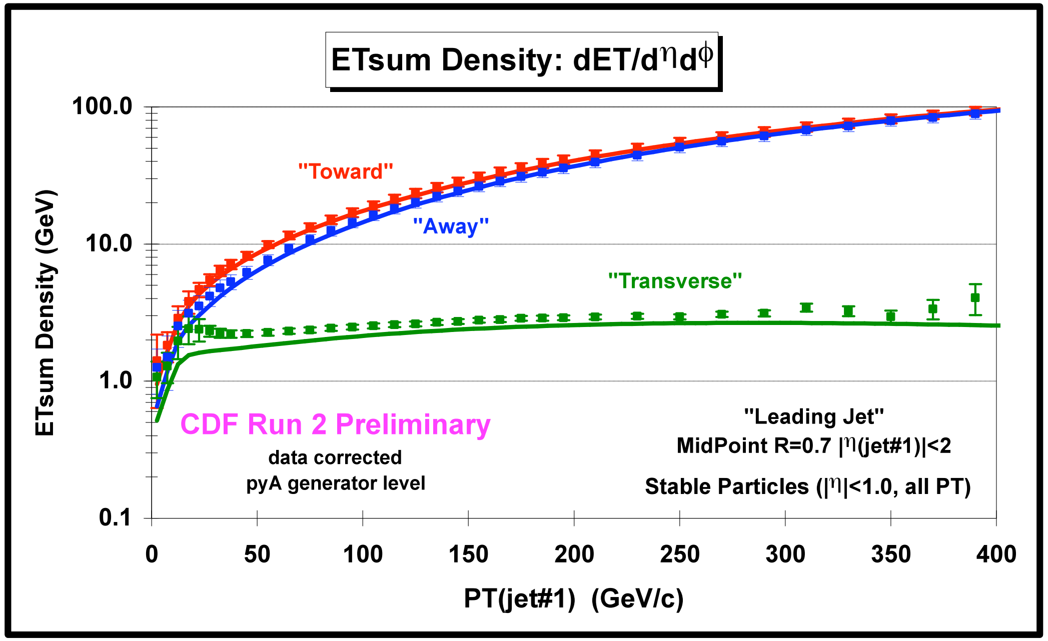
NLO prediction closest to the data
(once again one needs UE contribution to
bring NLO predictions to the data)

Underlying Event Studies





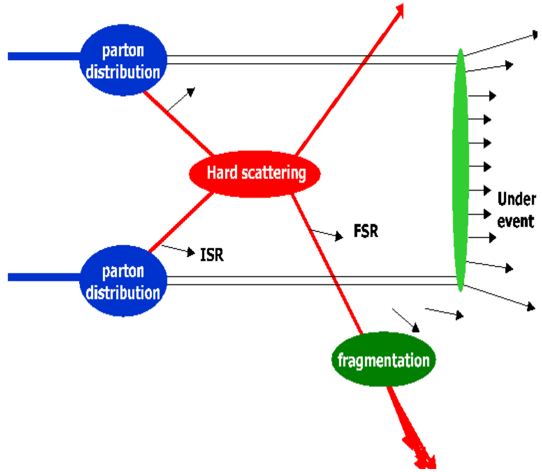
$$p_T^{track} > 0.5\,\text{GeV}, \quad |\eta^{track}| < 1$$

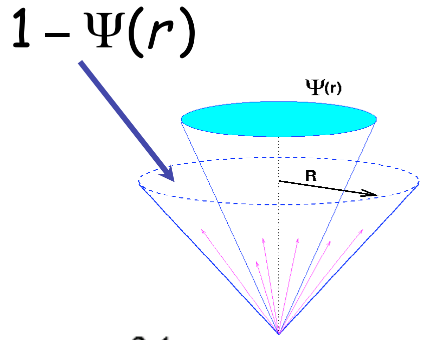


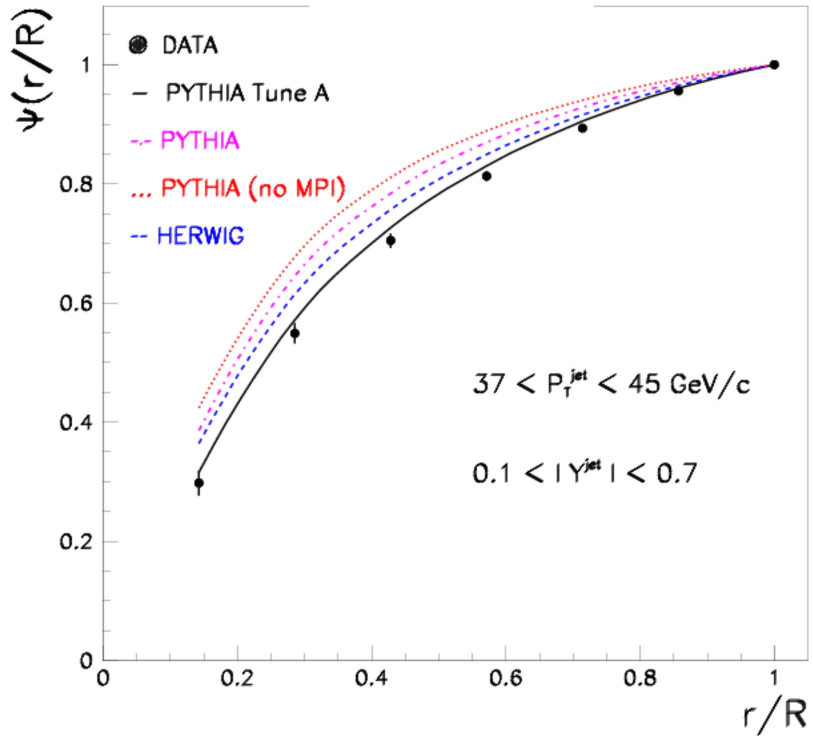
transverse region sensitive to soft underlying event activity

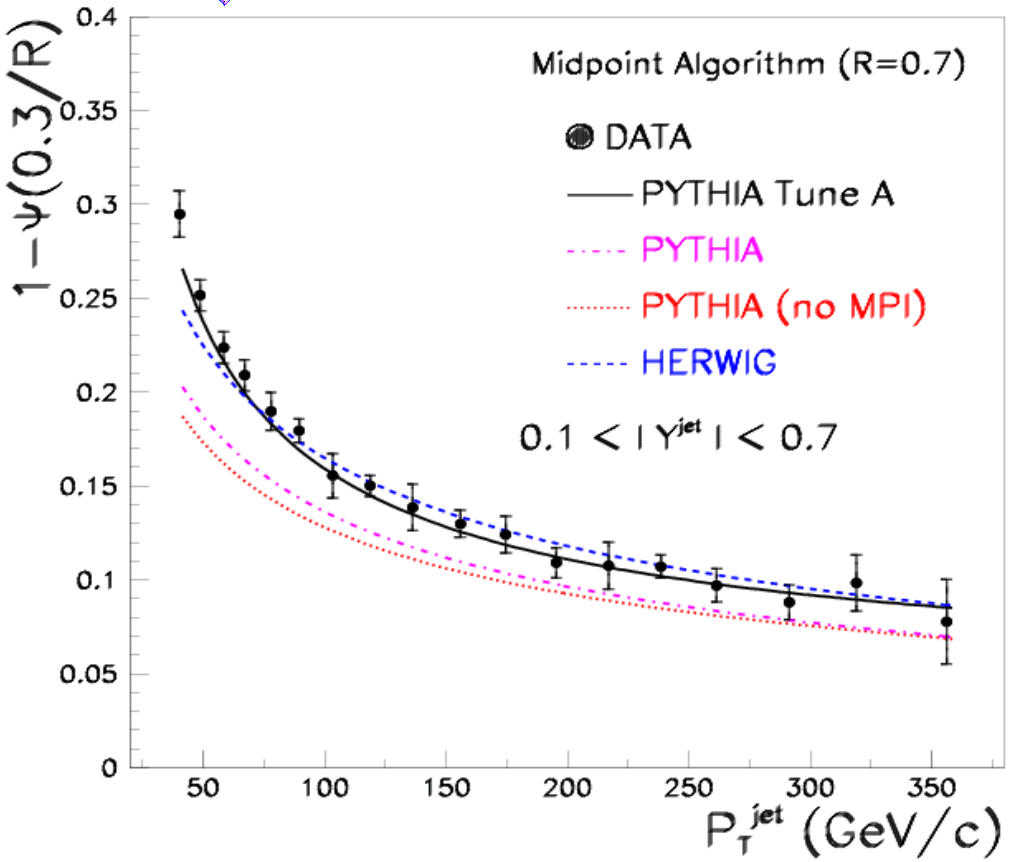
Good description of the underlying event by PYTHIA after tuning the amount of initial state radiation, MPI and selecting CTEQ5L PDFs (known as PYTHIA Tune A)

Jet shapes







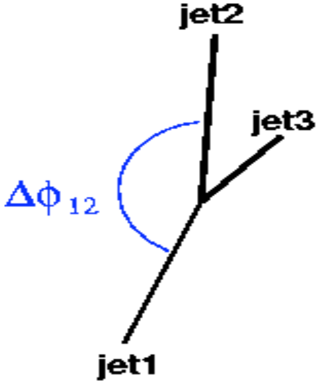


- PYTHIA Tune A describes the data (enhanced ISR + MPI tuning)
- PYTHIA default too narrow
- MPI are important at low Pt
- HERWIG too narrow at low Pt

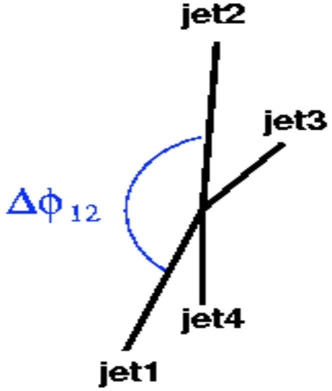
We know how to model the UE at 2 TeV for QCD jet processes

Studies on $\Delta\phi$ between jets

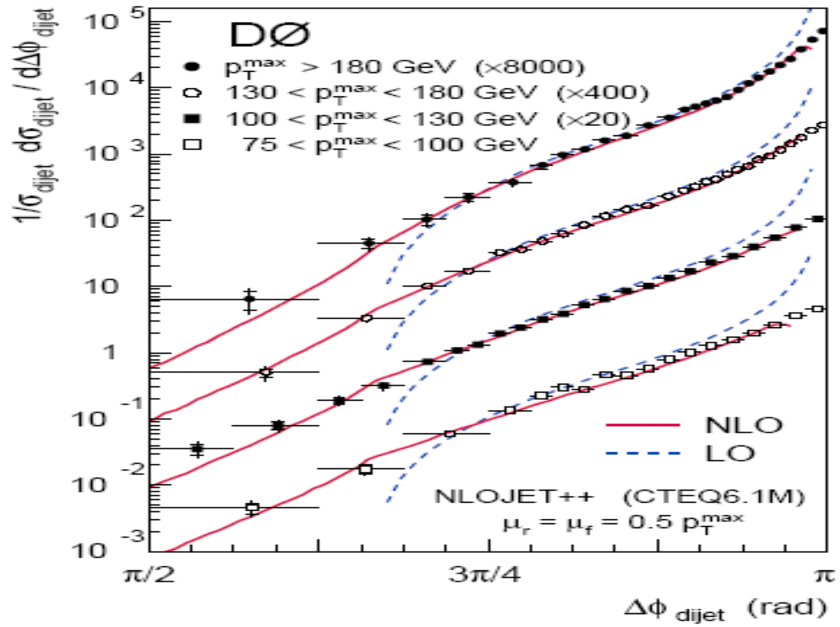
Using the Midpoint Jet Algorithm

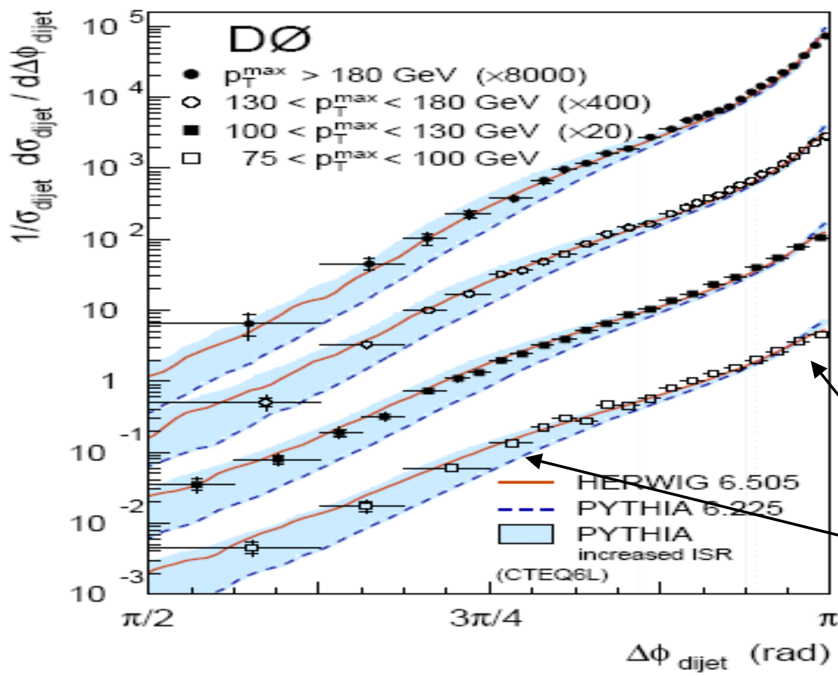


LO in $\Delta\phi$



NLO in $\Delta\phi$





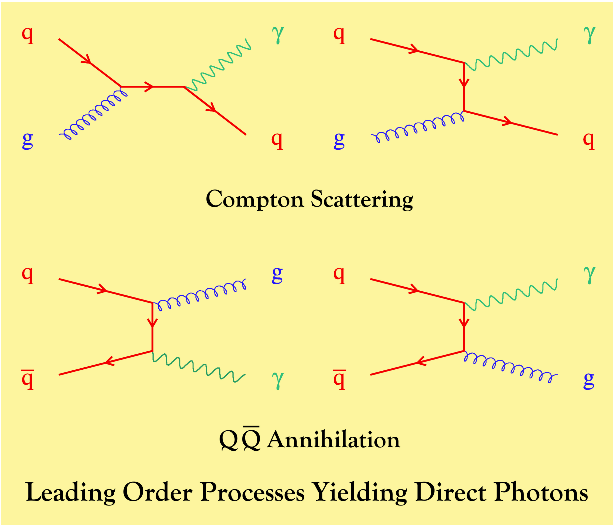
LO dominated by collinear topologies

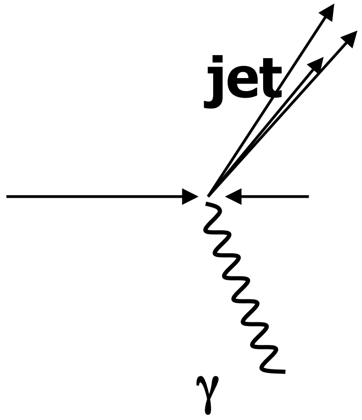
NLO closer to the data

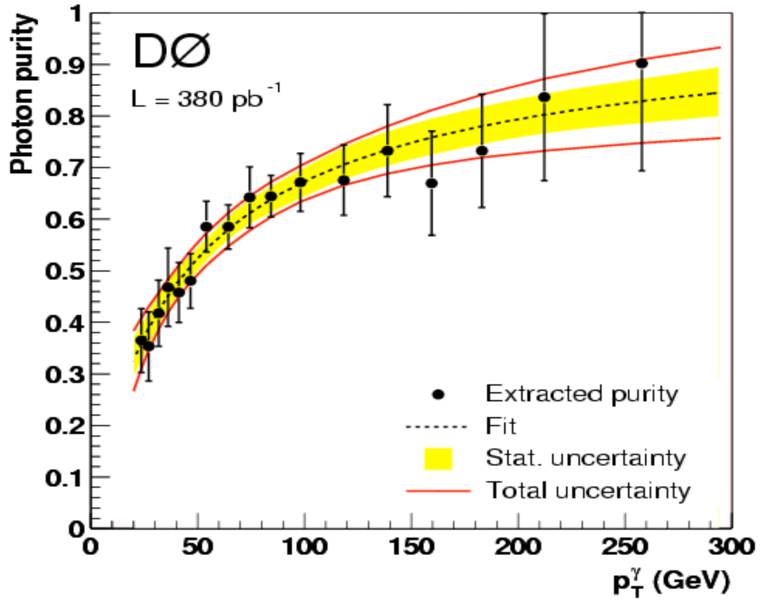
(region around π requires soft gluons…)

Sensitive to implementation of ISR of soft gluons in parton shower MCs

Prompt Photon Production

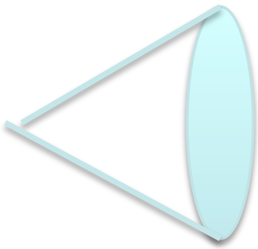


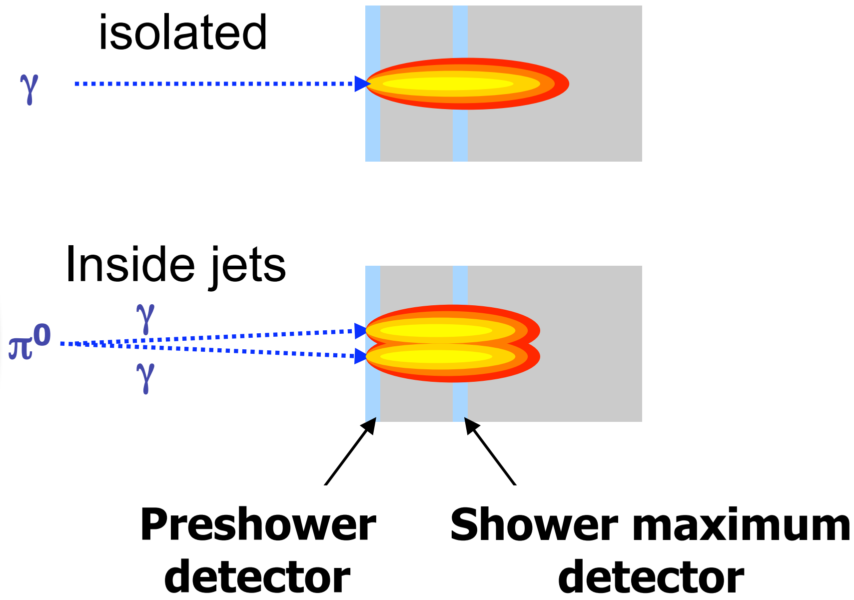




Using prompt photons one can precisely study QCD dynamics:

- Well known coupling to quarks
- Give access to lower Pt
- Clean: no need to define "jets"
- constrain of gluon PDF

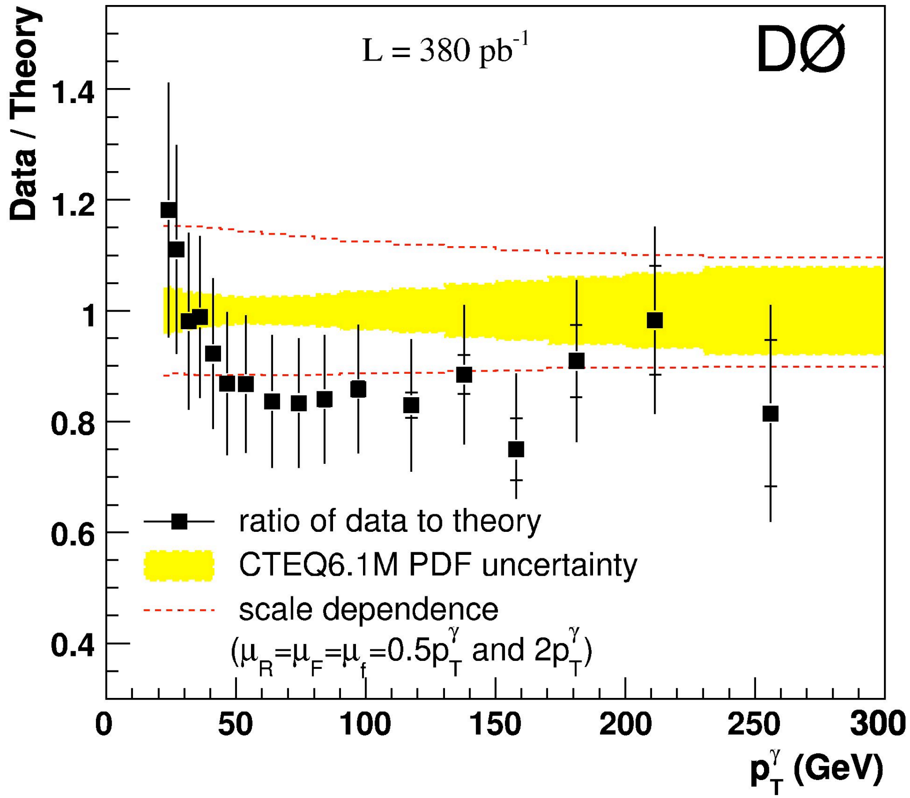


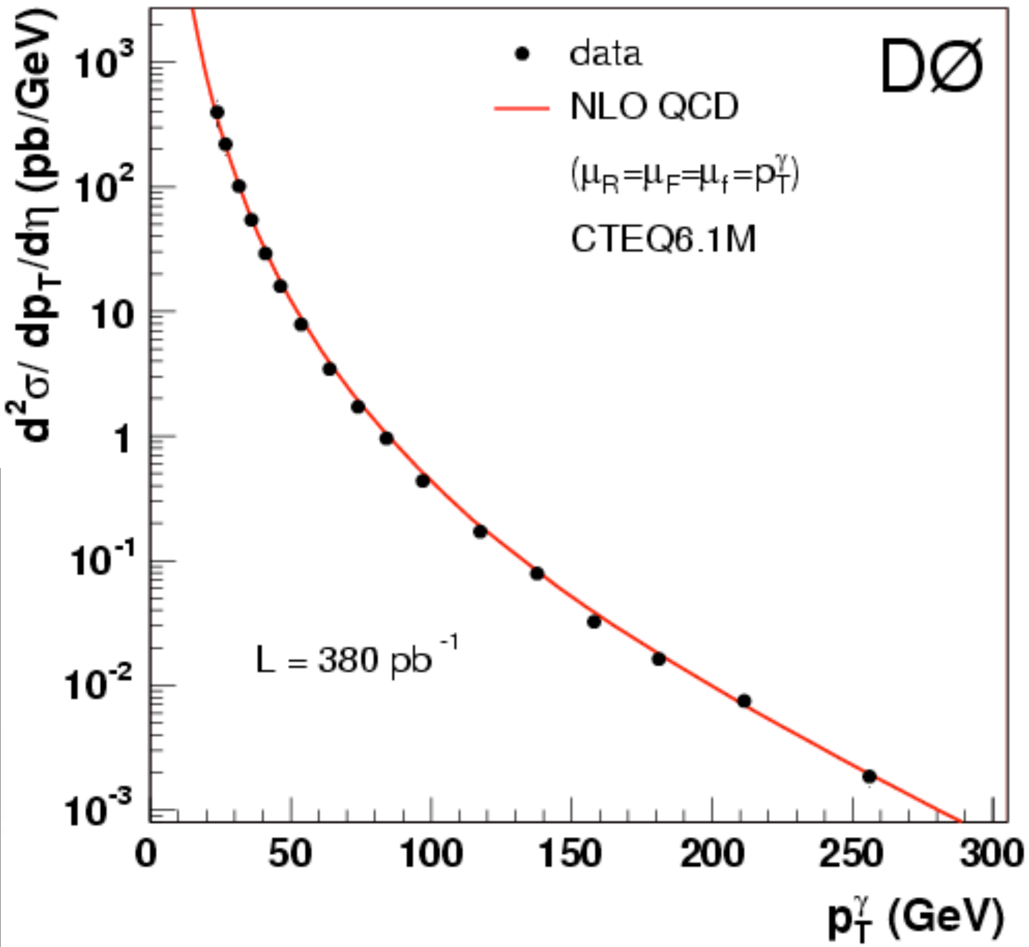


Experimentally difficult because of large background from π^0 decays

Pt Distribution of Photons

Isolated photons
$P_t > 23$ GeV/c, $|\eta| < 0.9$
Photon signal extracted using a NN



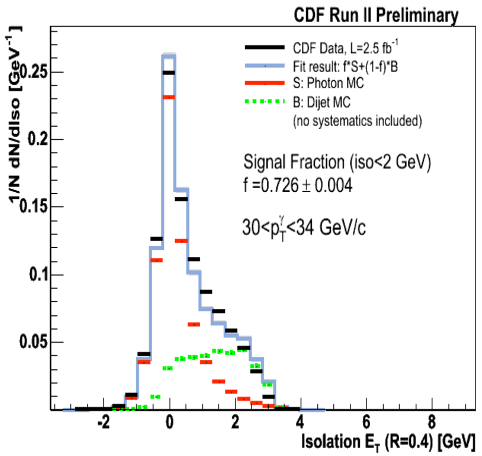


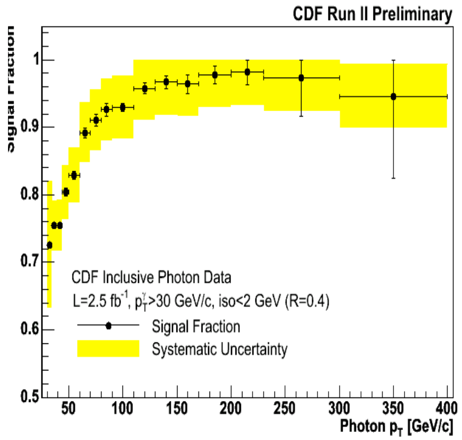
Agreement with NLO pQCD
"within quoted systematic uncertainties"

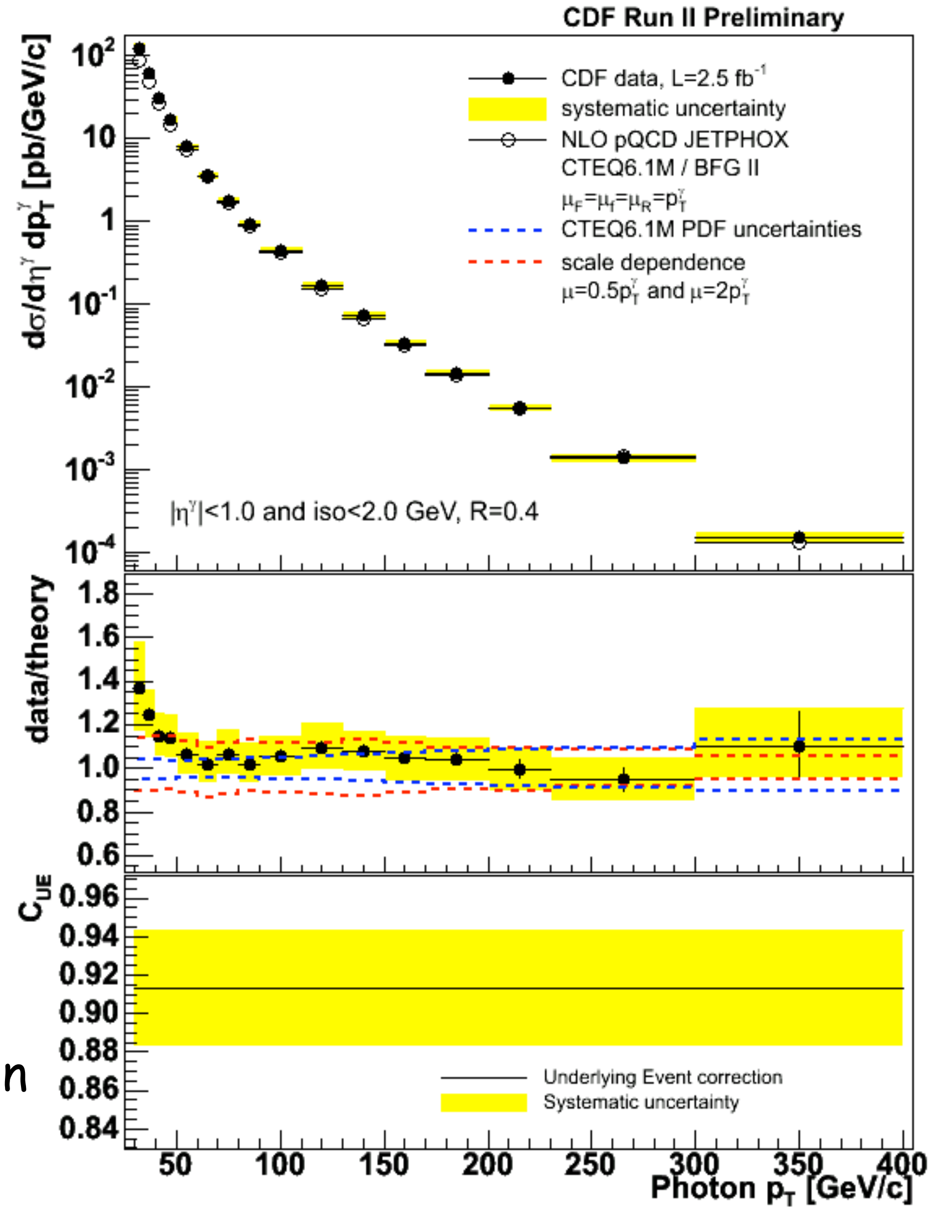
(the shape at low Pt not quite followed by the theoretical predictions)

CDF Inclusive Photon Result

Isolated photons (E_T in R= 0.4 < 2 GeV)
P_t> 30 GeV/c, $|\eta|$ < 1.0







New CDF result based on 2.5 fb^{-1}

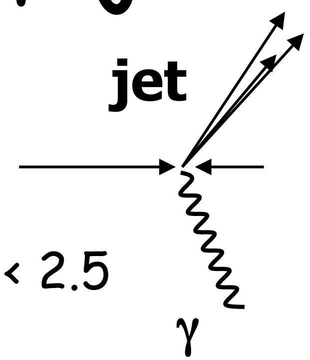
Agreement with NLO pQCD
(similar known shape at low P_t)

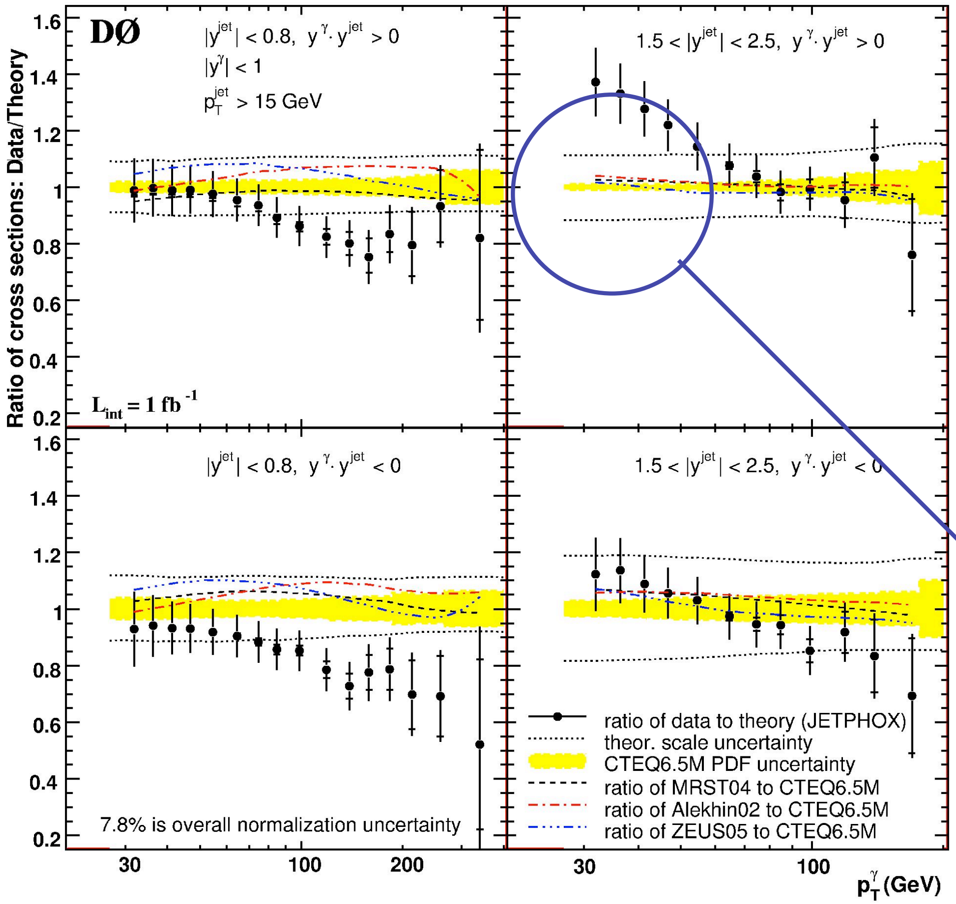
In CDF analysis the NLO pQCD prediction
is corrected for non-pQCD effects
from the UE affecting the isolation

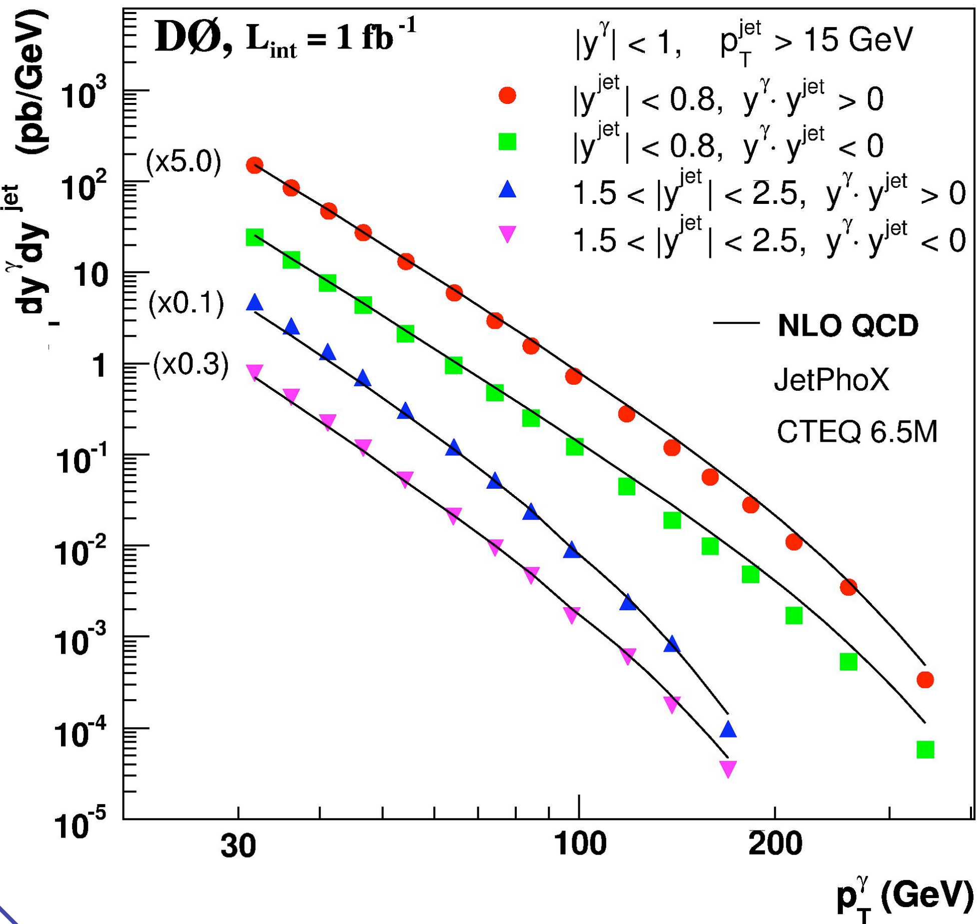
γ+jets results

Isolated photons
$P_t > 30$ GeV/c, $|\eta| < 1.0$

Jets with $P_t > 15$ GeV/c
$|\eta^{jet}| < 0.8$ or $1.5 < |\eta^{jet}| < 2.5$



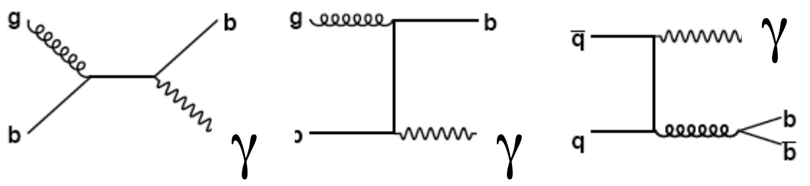




NLO pQCD prediction not really able to follow the data in some regions of the photon-jet phase space…

Very interesting for theorist if CDF could provide similar results…

γ + b/c



Isolated photons

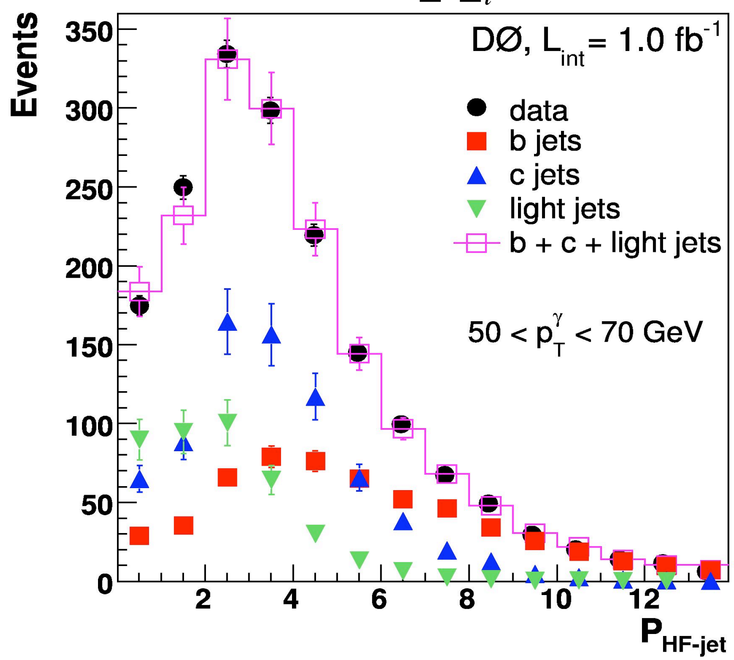
$P_t > 30$ GeV/c, $|\eta| < 1.0$

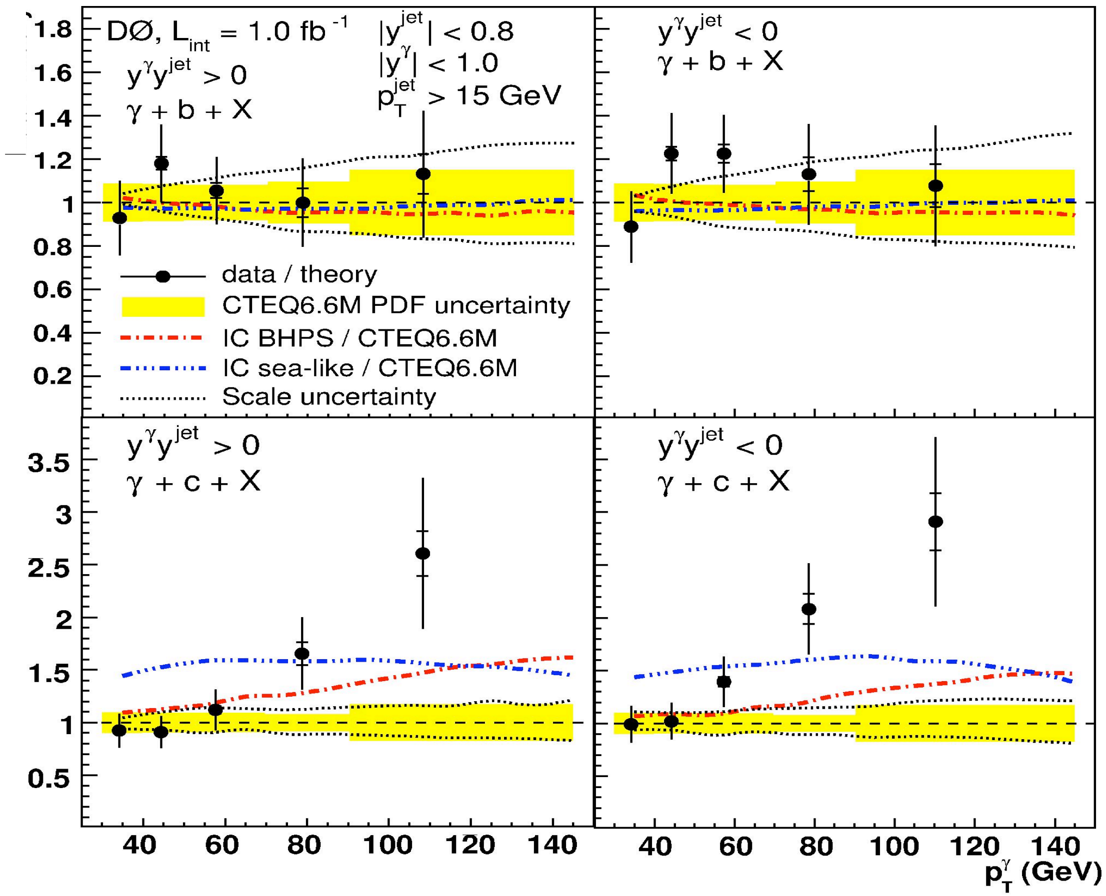
Jets with $P_t > 15$ GeV/c , $|\eta^{jet}| < 0.8$

Light quark suppressed using NN

Separation of light/b/c based on

$$P_{\text{HF-jet}} = -\ln \prod_i P^i_{track}$$





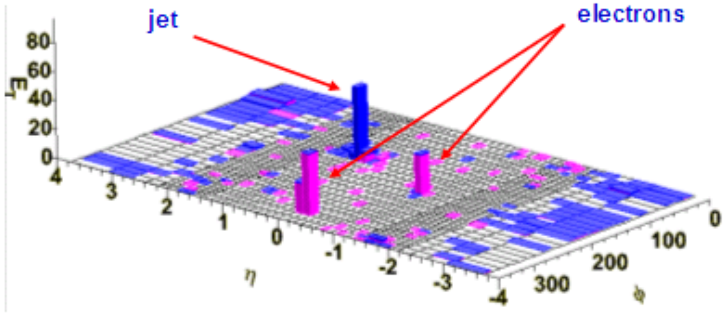
Good agreement with NLO pQCD for γ+b

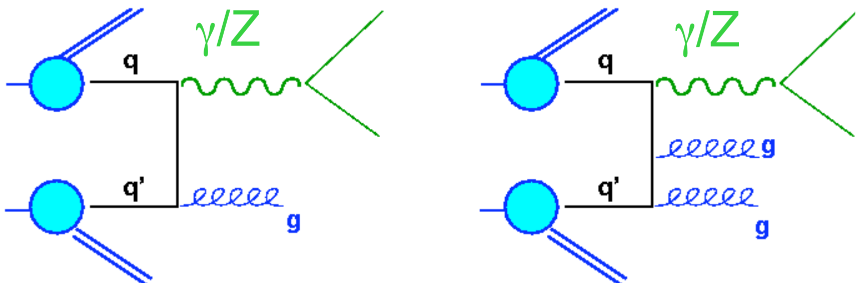
Disagreement for γ+c at large Pt

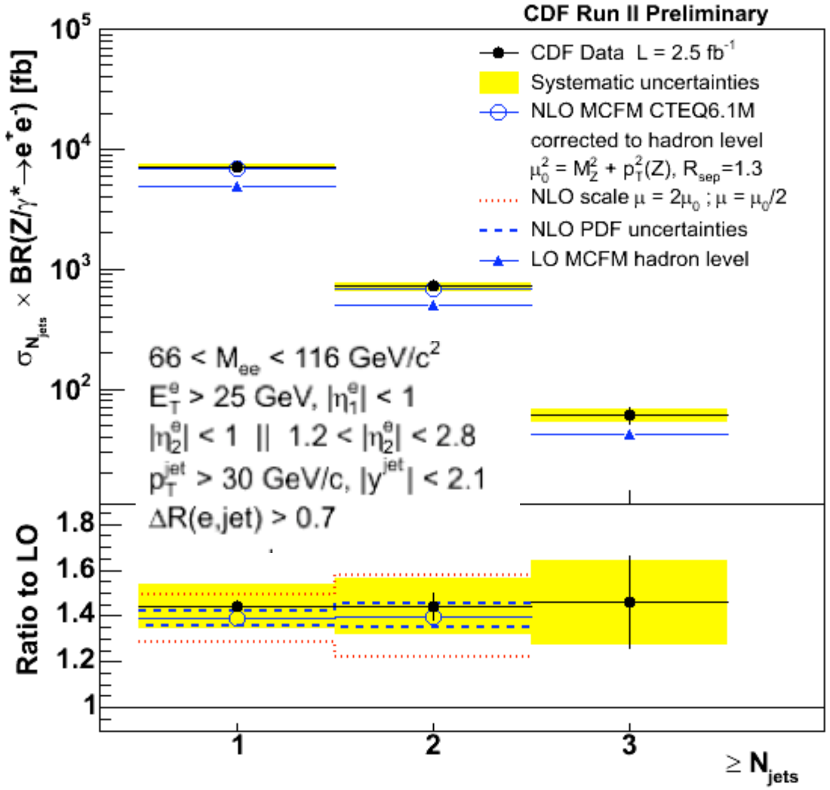
- Not covered by models with intrinsic charm
- Maybe related to γ+gluon->$Q\bar{Q}$ (which is dominant at large P_t) ?

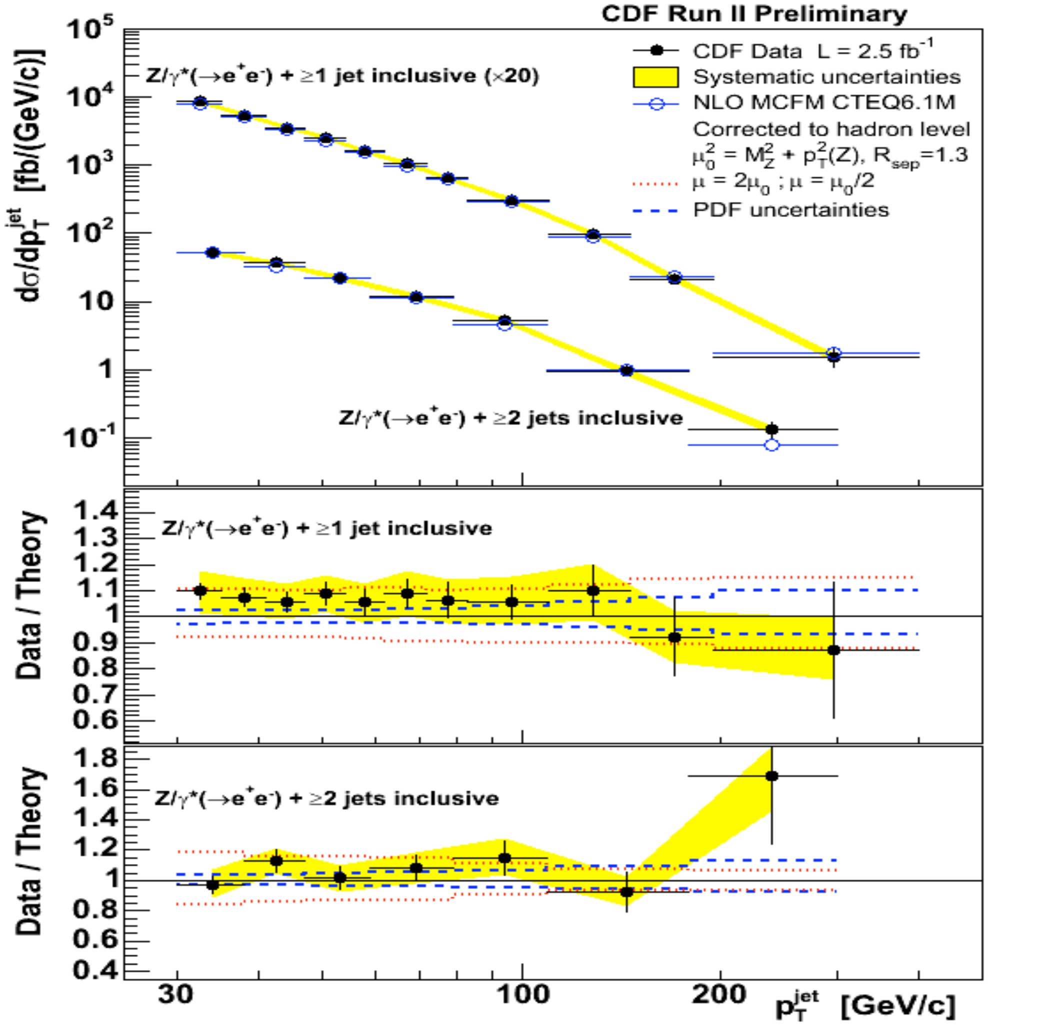
$Z/\gamma^*(\to ee)$ +jet(s)

Clean and allows to validate $Z \to \nu\nu$+jets bkgs.



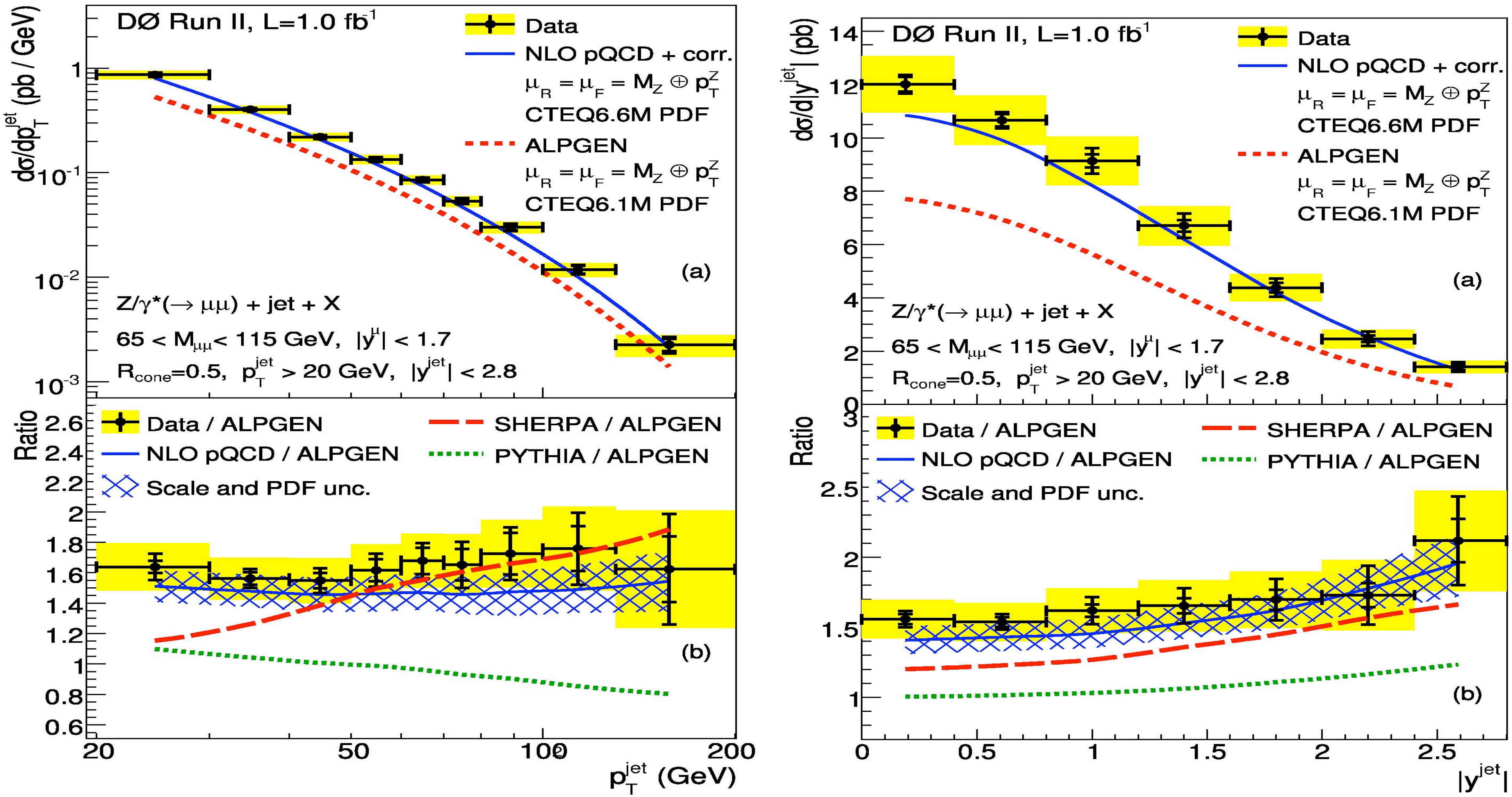






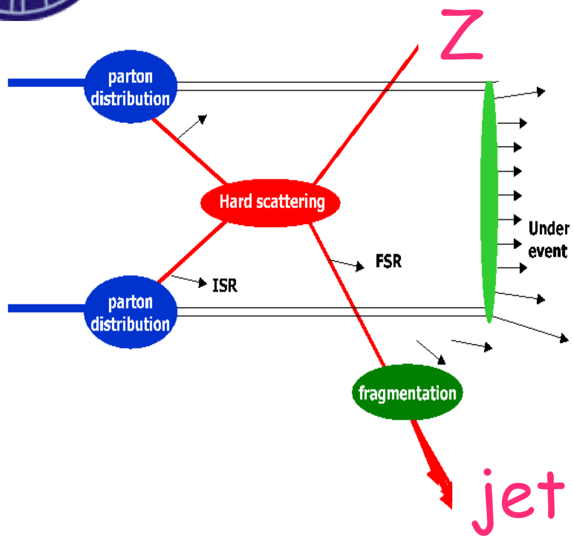
Good agreement with NLO pQCD predictions including non-pQCD corrections

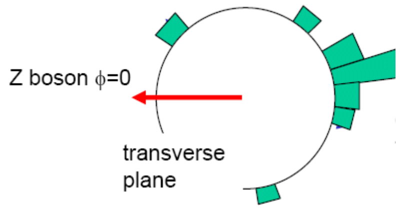
Z/γ*(-> μμ) +jet(s)

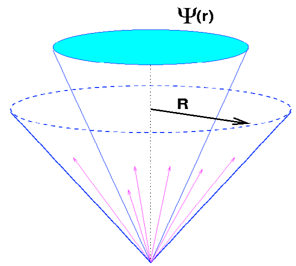


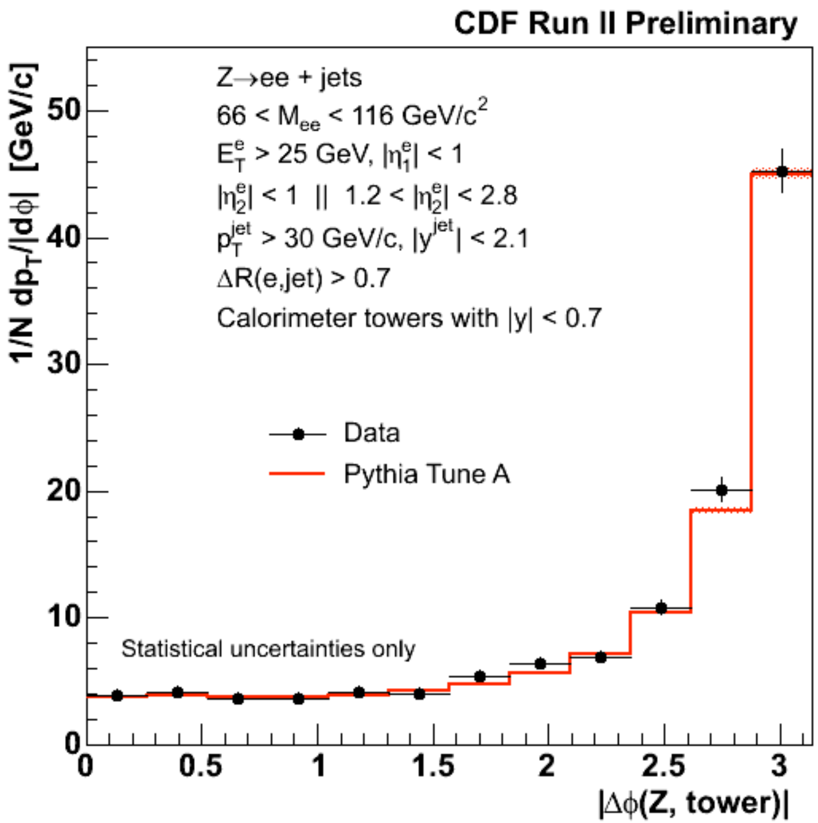
- Data described by NLO pQCD
- PYTHIA and ALPGEN below the data (consistent with LO prediction)
- SHERPA in between LO and NLO predictions (better at large Pt)

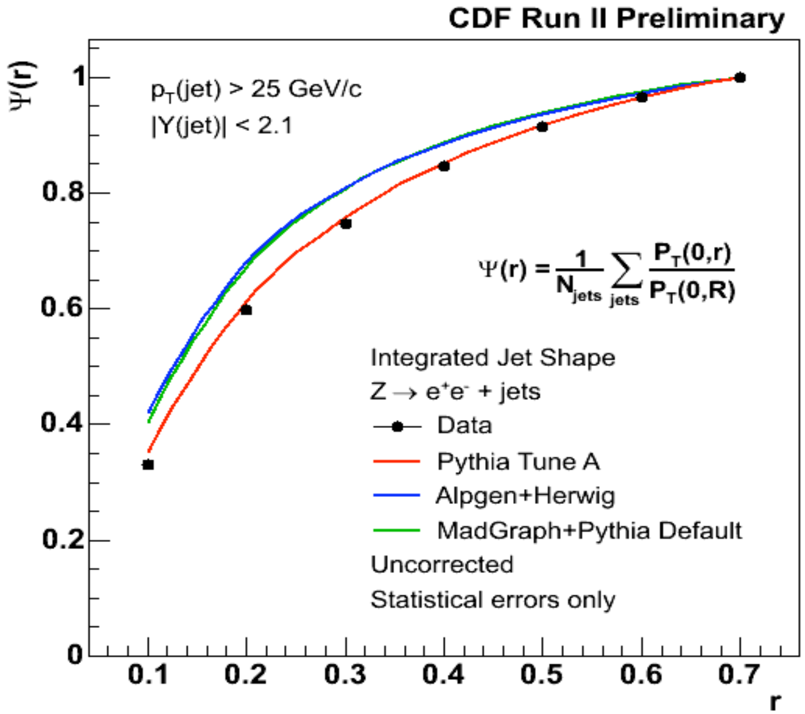
Soft radiation in Z+jet(s)





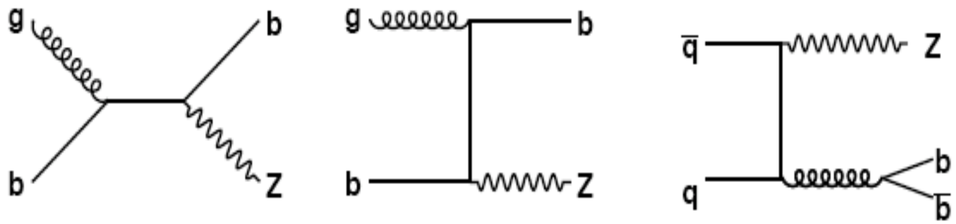






Implementation of proper modeling of UE still needed in new W/Z+Jet(s) Monte Carlos....very important

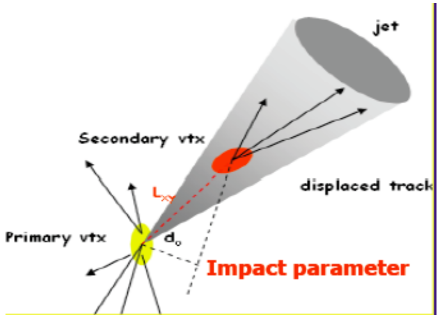
LHC will use "extra jets" veto in Higgs analyses to reduce QCD bckg.

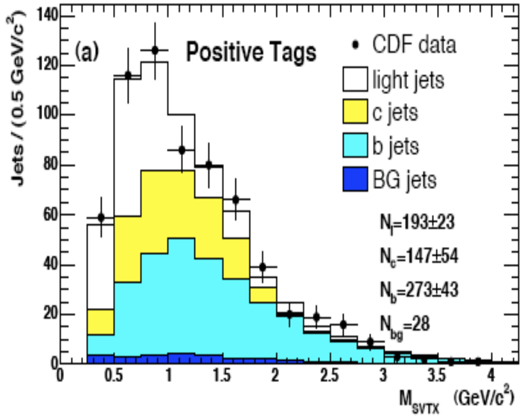


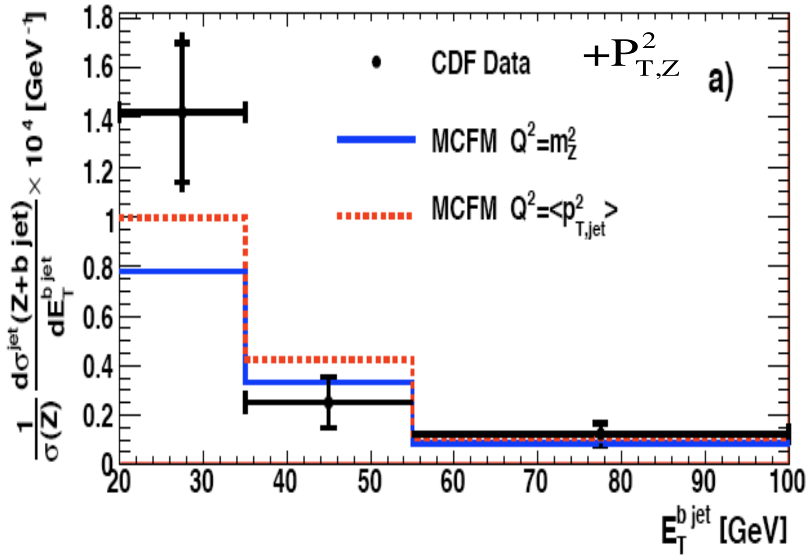
Inclusive Z+b

Test of background for Higgs / SUSY

Considering both electron and muon channels and jets with Et > 20 GeV and $|\eta|$ < 1.5







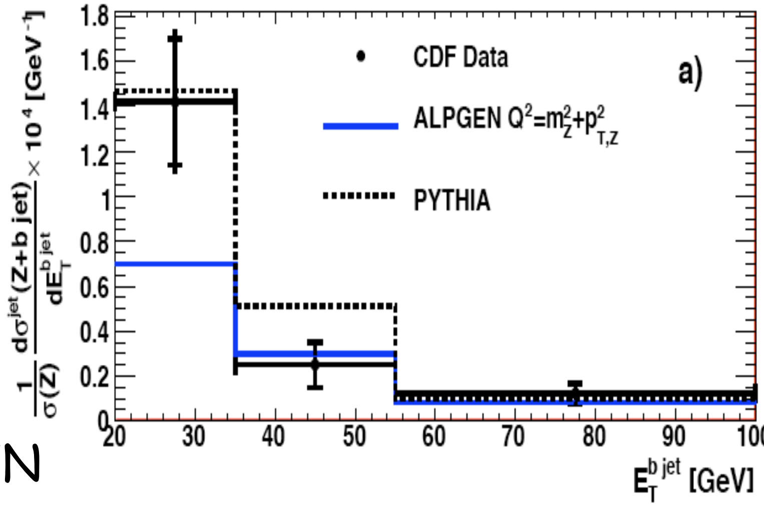
$$\frac{\sigma(Z+b)}{\sigma(Z+jets)} = 2.08 \pm 0.33 \pm 0.34(\%)$$

$$MCFM: 1.8\%\ (Q^2 = M_Z^2 + P^2_{T,Z})\ ;\ 2.2\%\ (Q^2 = \ \langle P^2_{T,Jet} \rangle)$$

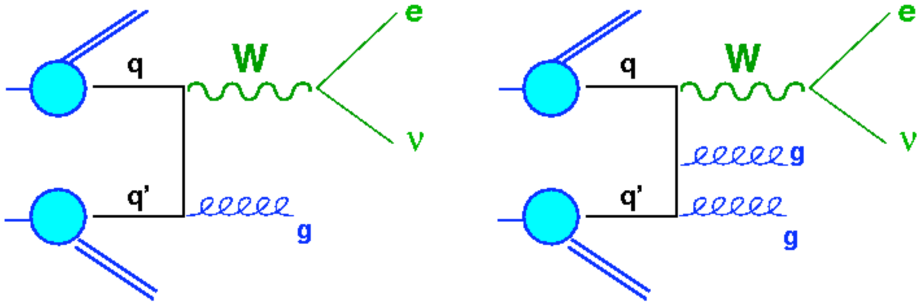
Measurements in agreement with predictions (large uncertainties in both data and theory)

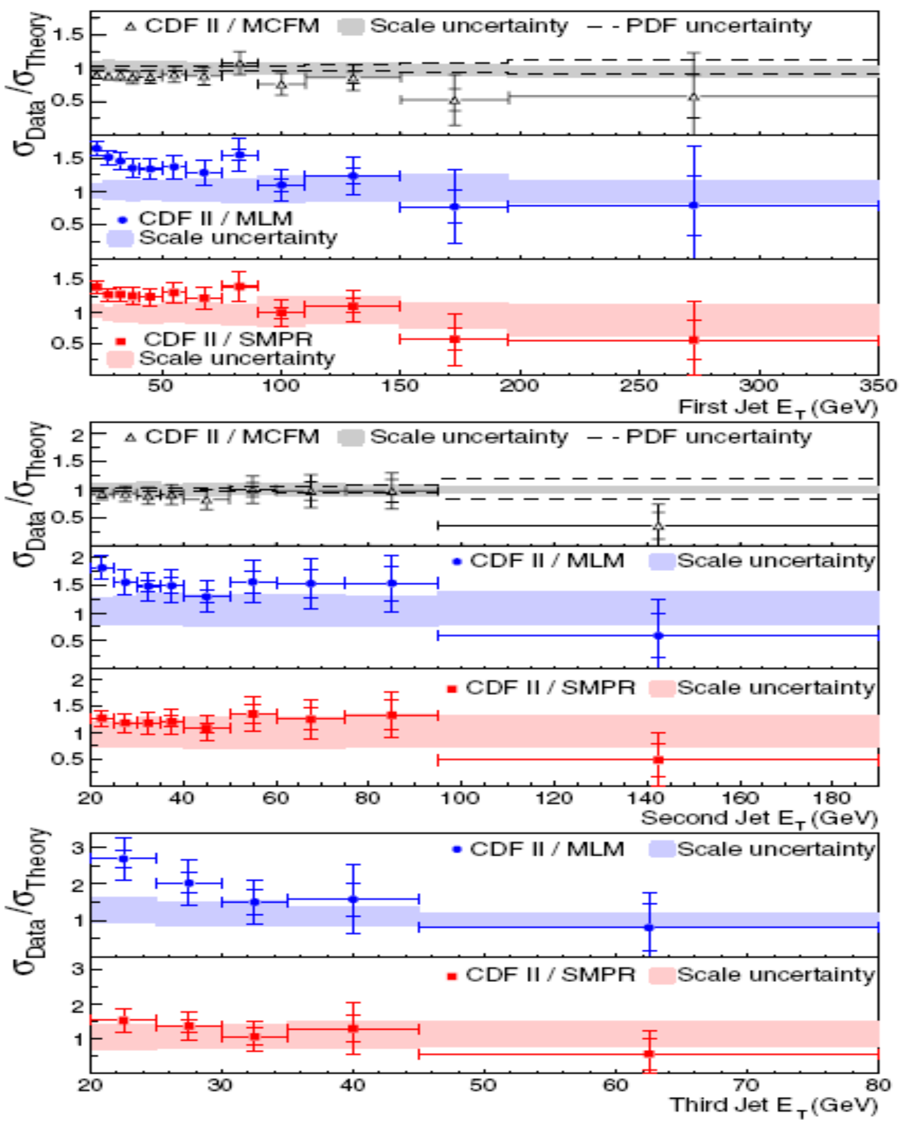
→No complete NLO prediction in the Z+b$\bar{b}$ case translates into a large scale dependence

Also large variations between PYTHIA and ALPGEN

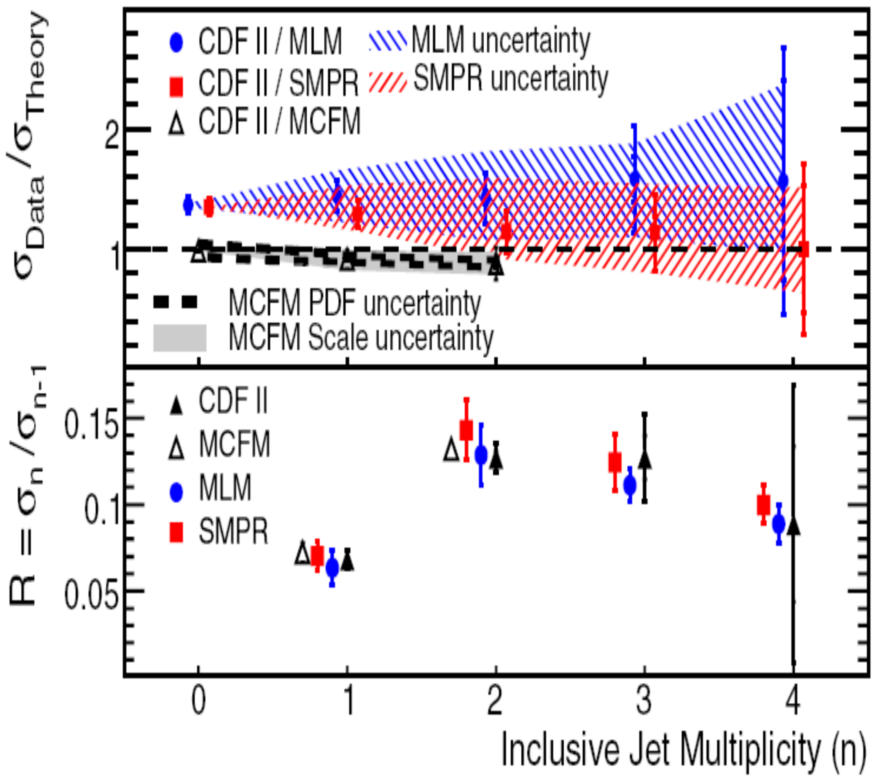


W+jet(s) Production



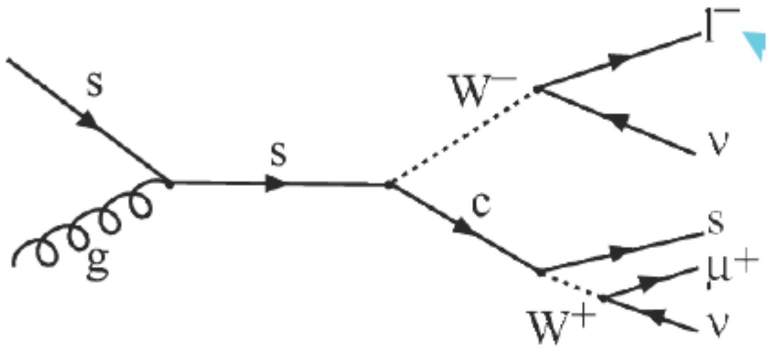


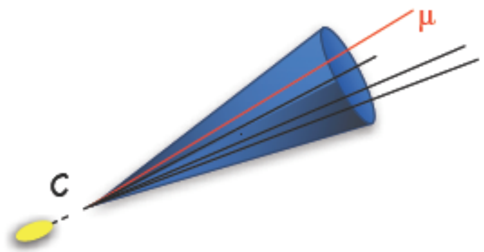
x 10 more cross section than Z+jets
But requires to control QCD and Top bkgs.
(real risk to tune the MCs against SUSY)



Good agreement with pQCD NLO calculation (includes non-pQCD effects)
At low P_T Monte Carlo needs a better modeling of UE (ALPGEN+PYTHIA)

W+c



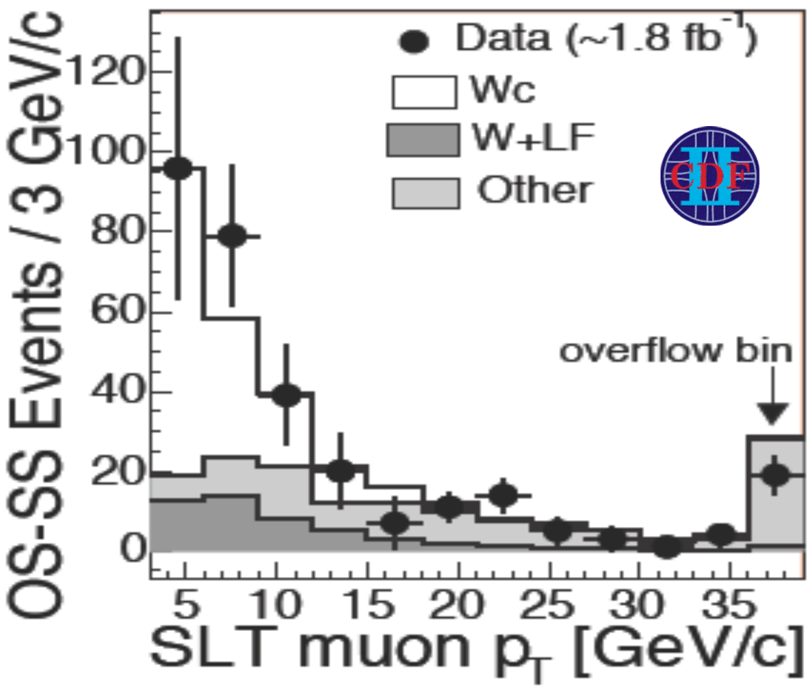


Use charge correlation between leptons
To obtain the signal W+c from OS-SS

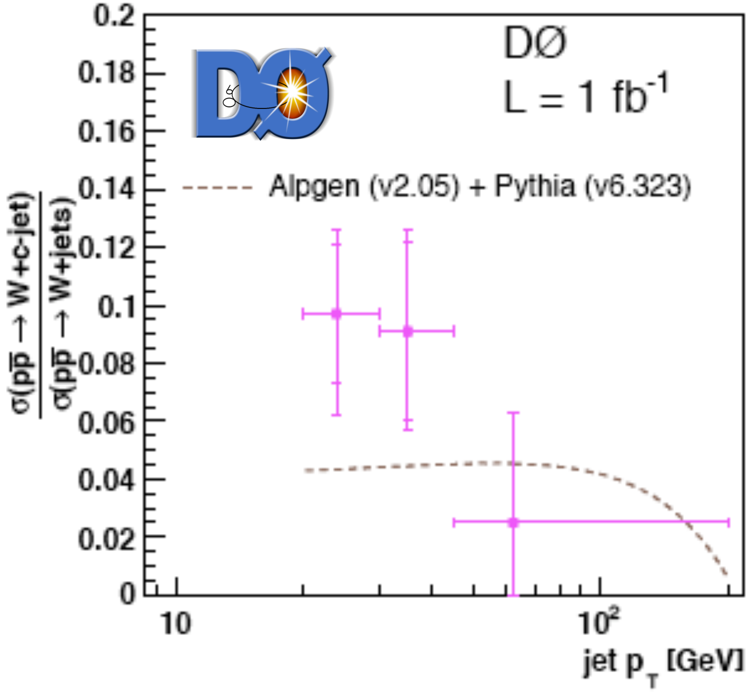
Events with a high-pt lepton, MET/MT
and at least a jet with a soft pt lepton

$$\sigma_{Wc} x Br(W \to l\nu) = 9.8(stat.) \pm 2.8^{+1.4}_{-1.6}(syst.)\, pb$$

$$NLO: 11.0^{+1.4}_{-3.0}\, pb\ (p_{Tc} > 20\ GeV/c,\ |\eta_c| < 1.5)$$



D0 uses both e and μ soft leptons
For jets with Pt > 20 GeV, |η|<2.5
W+c/W+jets agrees with LO pQCD



Final Notes

- **Inclusive Jet measurements in Run II contributed to a better understanding of the gluon PDF**
  →less gluons at large X now preferred !

- **Proper Modeling of the Underlying Event**

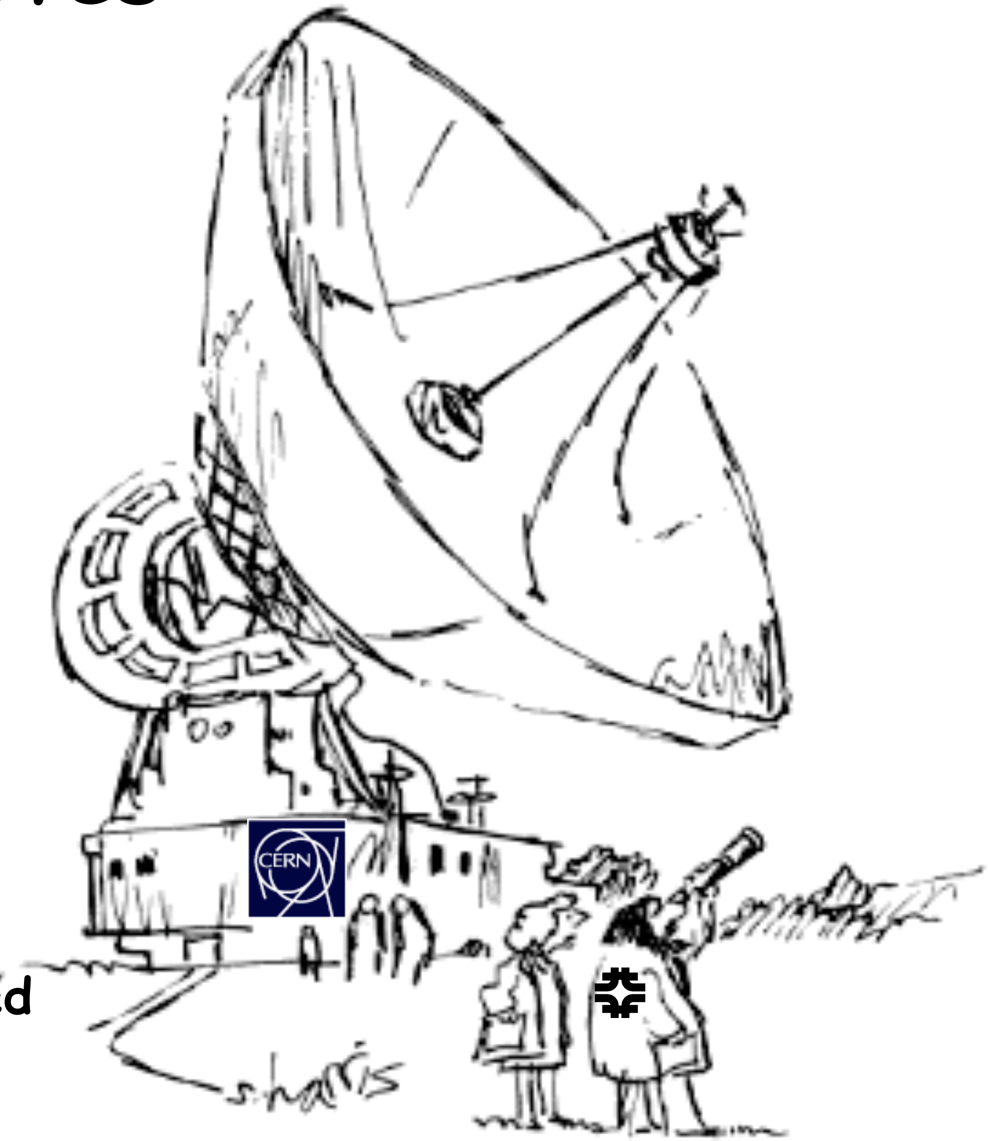
- **Photon + Jet results suggest some disagreements with pQCD NLO**

- **Z/W+jet(s) results test background estimations in searches for new physics**

- **First Z/W+HF measurements start challenging large theoretical uncertainties**
  → More data and better predictions needed

- **Tevatron promises 8 fb^{-1} by End 2009**

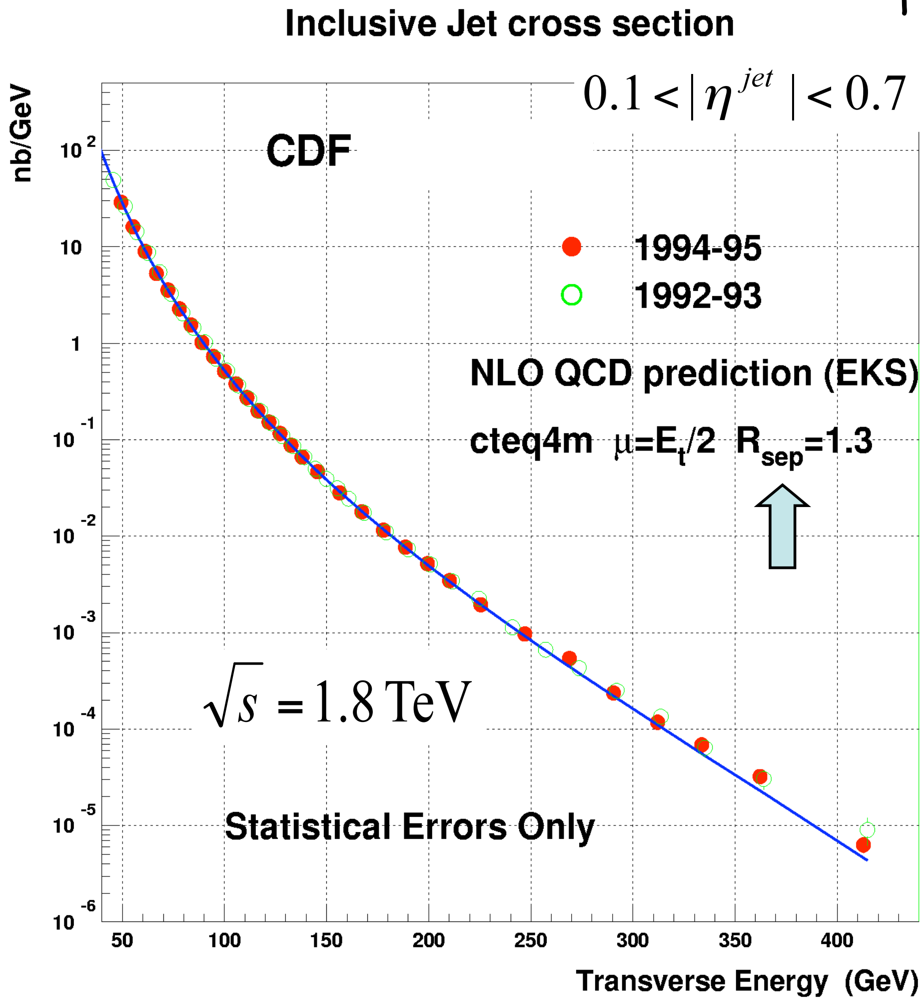
- **First LHC physics results by End 2009 ….**

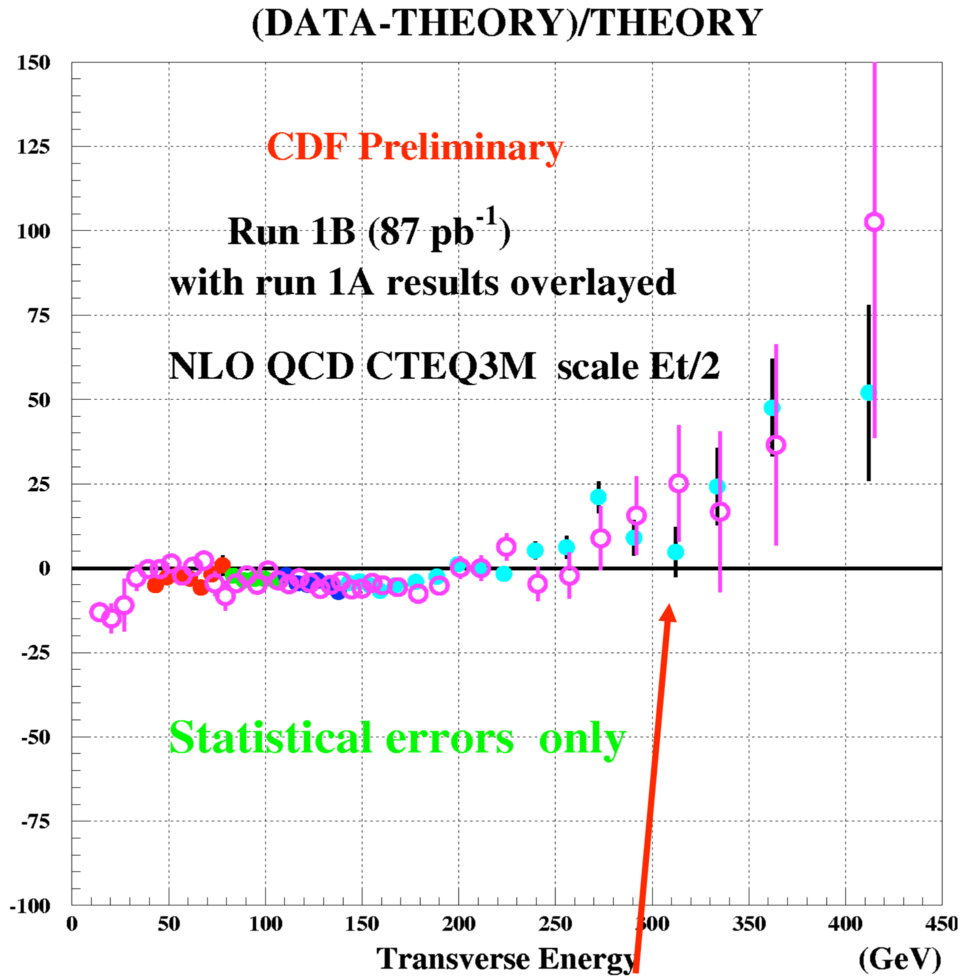


"Just checking."

Backup Slides

Run I $\frac{d\sigma}{dE_T^{JET}}$ Results



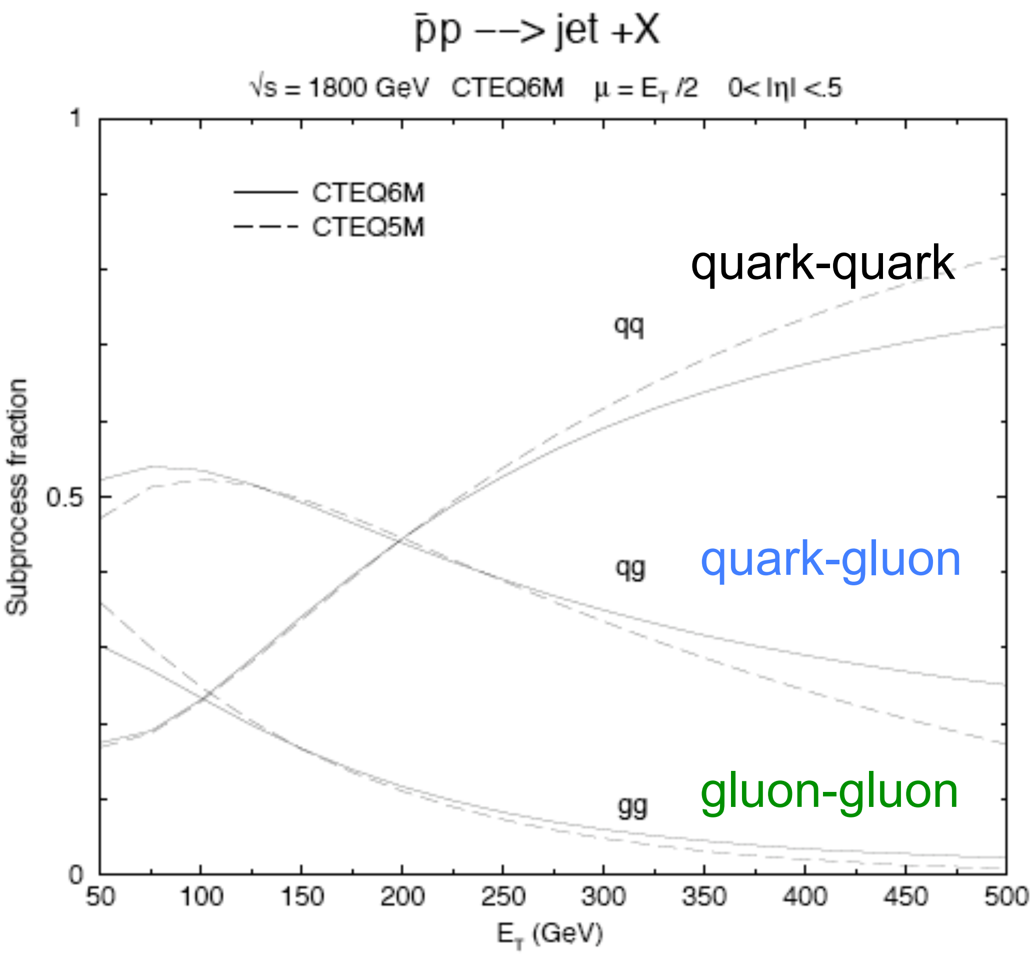


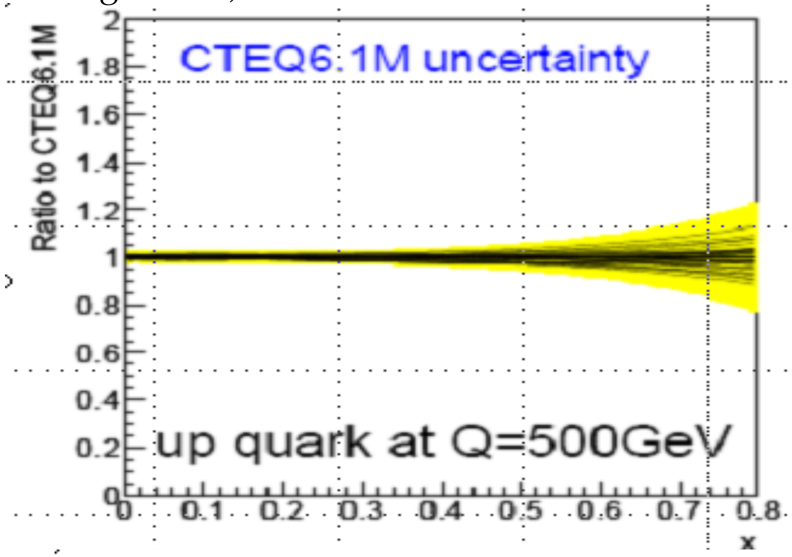
Run I data compared to pQCD NLO

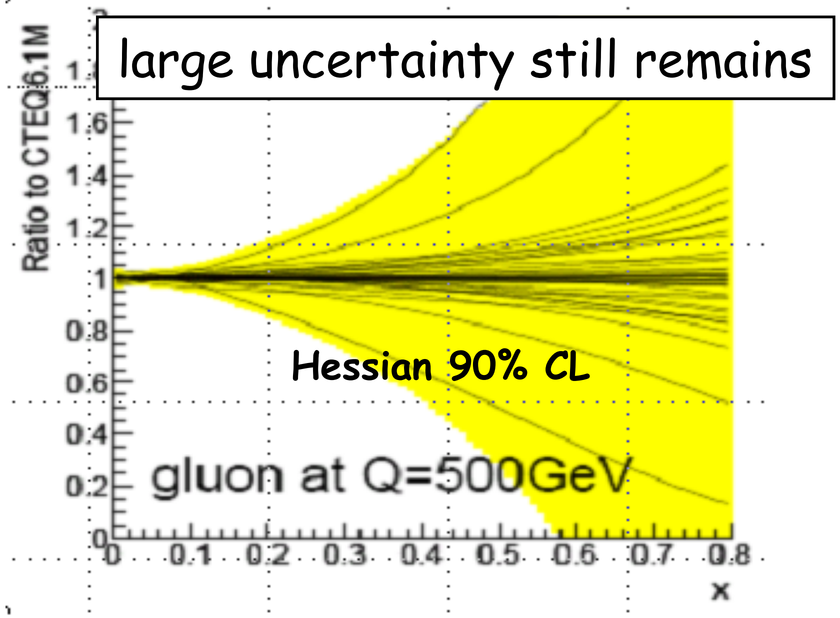
Observed deviation in tail ....
was this a sign of new physics ?

gluon PDFs at high-x

$$\sigma = \sum \int dx_1 dx_2 f_q(x_1, Q^2) f_g(x_2, Q^2) \sigma^{parton}$$



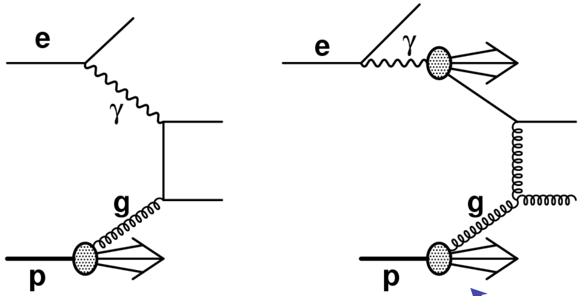


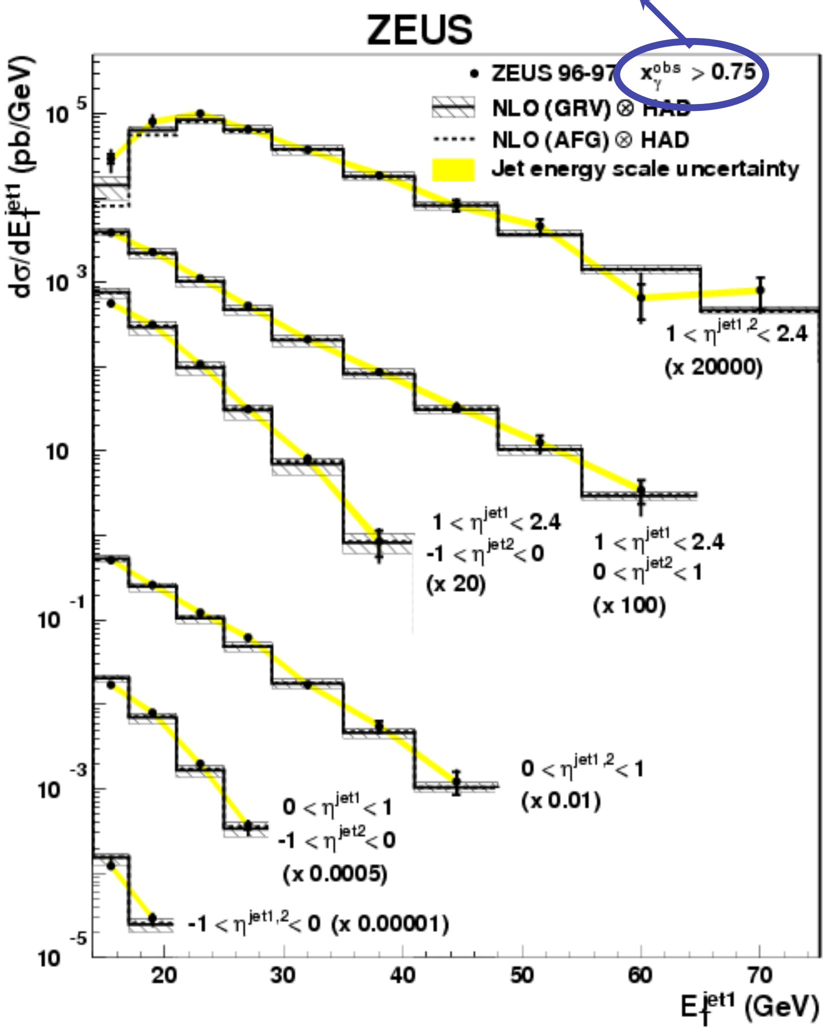


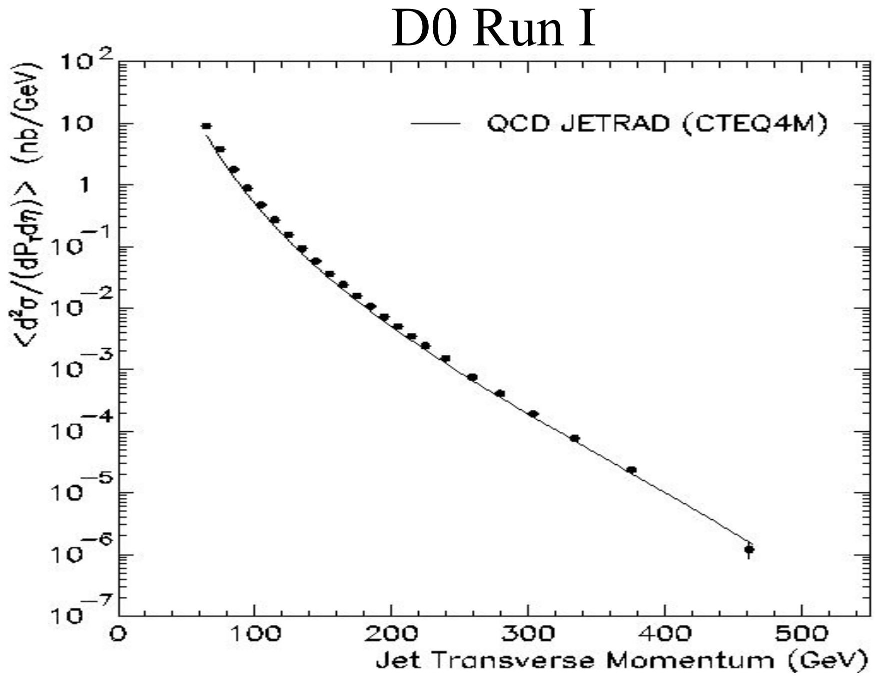
Important GG and GQ contrib. at high-E_T

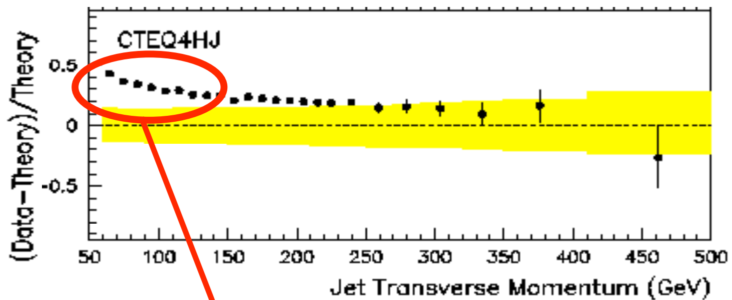
…room for SM explanation….

Results from ZEUS / D0 Run I









Disagreement at low p_T

↳ Suggests Underlying Event not properly accounted for